ME 3823 (2018S) MACHINE ELEMENTS DESIGN

POWER TRANSMISSION DESIGN PROJECT

<u>GROUP MEMBER</u>

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1. Design Requirements

Design a two-stage speed reducer that will take 62 hp of power from the shaft of an electric motor rotating at 1200 rpm and deliver it to a machine that is to operate at approximately at 155 rpm. An overall reliability of 95 % and a design life of 20,000 h are desired. A design factor 1.5 is used.

Table 1. Gear Ratio and Torques.

Gear Ratio (e):	**0.128**
Torque on input shaft (lbf-ft):	**1705**
Torque on output shaft (lbf-ft):	**13367**
Torque on intermediate shaft (lbf-ft):	**4774**

2. Gear Design

Table 2. Gear Specifications

Parameters	**Gear 2**	**Gear 3**	**Gear 4**	**Gear 5**
W^t (lbf)	**1302.5**	**1302.5**	**3647.1**	**3647.1**
W^r (lbf)	**474.1**	**474.1**	**1327.4**	**1327.4**
P	**3**	**3**	**3**	**3**
d (in)	**5**	**14**	**5**	**14**
F (in)	**3**	**3**	**3**	**3**
σ_c (ksi)	**81.6**	**81.6**	**128.5**	**128.5**
σ_t (ksi)	**8.92**	**5.87**	**22.1**	**14.6**
Material type	**Steel Grade 1 Flame Induction Hardened**	**Steel Grade 1 Flame Induction Hardened**	**Steel Grade 2 Carburized and Hardened**	**Steel Grade 2 Carburized and Hardened**
S_c (ksi)	**170**	**170**	**225**	**225**
S_t (ksi)	**22**	**22**	**65**	**65**
n_c	**2.12**	**2.12**	**1.78**	**1.78**
n_t	**2.51**	**3.81**	**2.98**	**4.54**

[W^t: tangential force; W^r: radical force; P: diametral pitch; d: pitch diameter; F: face width; σ_c: contact stress; σ_t: bending stress; S_c: allowable contact stress number; S_t: allowable bending stress number; n_c: safety factor for wear; n_t: safety factor for bending.]

Part Vender Information

Part Specifications

Gears

Gear #	# of Teeth	Model #	Bore (in)
2	15	F 315A	1.313
3	42	F 342	1.25
4	15	F 315 A	1.313
5	42	F 342A	1.25

The CAD models for the gears were provided by RushGears.com. Note that the bores were altered to fit the diameter of the shafts.

Retaining Rings

Ring #	Groove Diameter	Groove Width	Model #
1	37.50 mm	1.85 mm	DNS 40
2	2.297 in	0.056 in	WS 237
3	37.50 mm	1.85 mm	DNS 40
4	37.50 mm	1.85 mm	DNS 40
5	2.924 in	0.039 in	VS 300
6	2.924 in	0.039 in	VS 300
7	47.05 mm	1.75 mm	ES 50
8	87.21 mm	1.73 mm	ES 90
9	4.188 in	0.068 in	WS 418
10	87.21 mm	1.73 mm	ES 90

All retaining rings provided by Smalley Steel Ring Company. Note rings are numbered from 1-10 with 1 being closest to the input and 10 being closest to the output.

Bearings

Bearing #	Bore Diameter (mm)	Width (mm)	Static Rating (N)	Model #
1	40	23	87000	22208MB
2	40	23	87000	22208MB
3	40	23	87000	22208MB
4	50	40	202000	22310 MB
5	90	24	108000	NU1018M
6	90	24	108000	NU1018M

All bearings provided by ATS bearing company. Note bearings are numbered 1-6 with 1 being closest to shaft input and 6 being closest to shaft output.

3. Shaft Design

Table 3. Shaft Specification

	Intermediate Shaft	Input Shaft	Output Shaft
Critical location (point labeled in V-M)	**Keyway**	**Keyway**	**Keyway**
Diameter at critical location (in)	**3**	**2.4**	**4.188**
Material type	**AISI 4340 Annealed**	**AISI 1045 Cold Drawn**	**AISI 1045 Cold Drawn**
Safety factor	**1.55**	**2.08**	**1.64**

Table 4. Intermediate Shaft Deformation

Point of Interest	XZ Plane	XY Plane	Total
Left bearing slope	**3.01e-6**	**6.76e-6**	**7.4e-6**
Right bearing slope	**2.23e-5**	**2.57e-5**	**3.4e-5**
Left gear slope	**3.66e-5**	**1.16e-4**	**1.21e-4**
Right gear slope	**5.35e-5**	**4.39e-5**	**6.92e-5**

Left gear deflection(in)	**5.43e-5**	**1.46e-4**	**1.56e-4**
Right gear deflection(in)	**9.04e-7**	**5.42e-6**	**5.44e-6**

Table 5. Input Shaft Deformation

Point of Interest	**XZ Plane**	**XY Plane**	**Total**
Left bearing slope	**8.4e-7**	**1.99e-5**	**7.1e-6**
Right bearing slope	**8.51e-6**	**1.85e-5**	**7.1e-7**
gear slope	**3.85e-5**	**1.85e-4**	**1.5e-4**
gear deflection(in)	**1.1e-4**	**1.05e-4**	**3.39e-5**

Table 6. Output Shaft Deformation

Point of Interest	**XZ Plane**	**XY Plane**	**Total**
Left bearing slope	**6.51e-6**	**4.22e-6**	**4.25e-5**
Right bearing slope	**5.96e-6**	**2.2e-6**	**2.9e-4**
gear slope	**3.16e-6**	**6.76e-6**	**3.5e-4**
gear deflection	**2.49e-6**	**2.69e-5**	**5.27e-5**

4. Bearing Design

Table 7. Bearing Specifications

	Radical force (lbf)	**Catalog load rating (lbf)**	**Bearing type**	**Bearing Vender**
Left bearing of intermediate shaft	**716.5**	**6492.7**	**Cylinder Roller**	**AST Bearings**
Right bearing of intermediate shaft	**2898.1**	**26260**	**Cylinder Roller**	**AST Bearings**
Left bearing of input shaft	**693.1**	**8552.8**	**Cylinder Roller**	**AST Bearings**
Right bearing of input shaft	**693.1**	**8552.8**	**Cylinder Roller**	**AST Bearings**
Left bearing of output shaft	**1940.6**	**12912**	**Cylinder Roller**	**AST Bearings**
Right bearing of output shaft	**1940.6**	**12912**	**Cylinder Roller**	**AST Bearings**

5. Supporting Information

5.1. Gear force and stress calculation for all gears

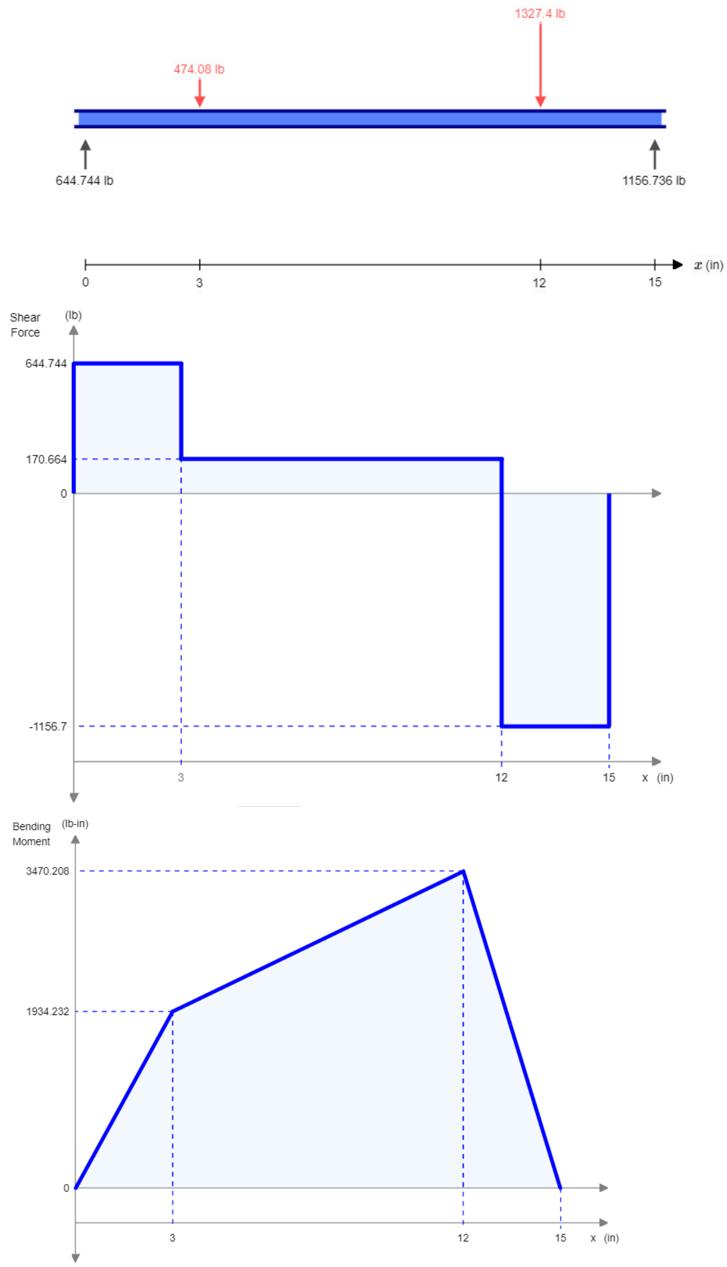
Please check attached MATLAB code.

5.2. V-M diagram of all shafts

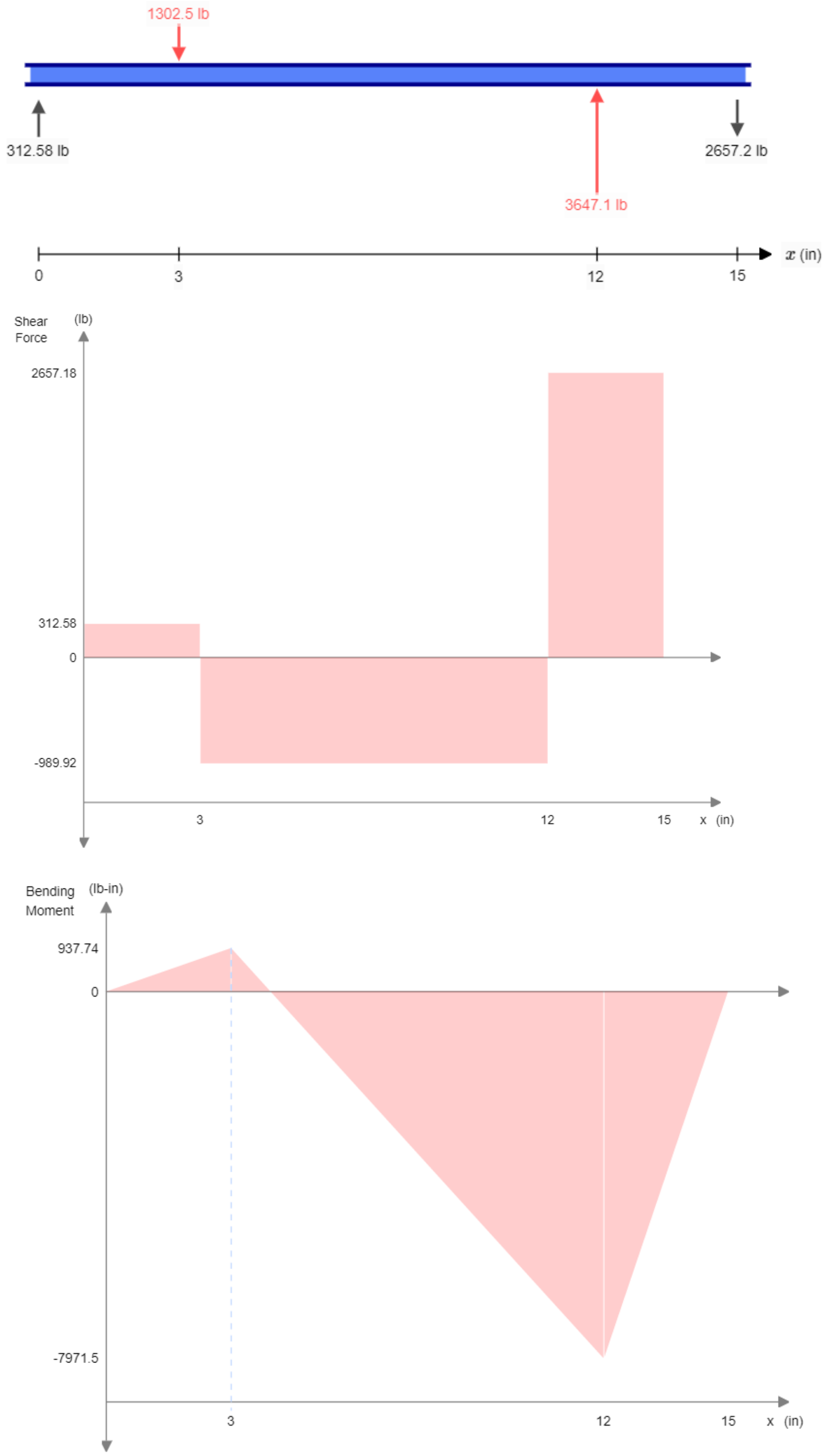
All combined Moment Diagrams shown in attached MATLAB code using piecewise functions.

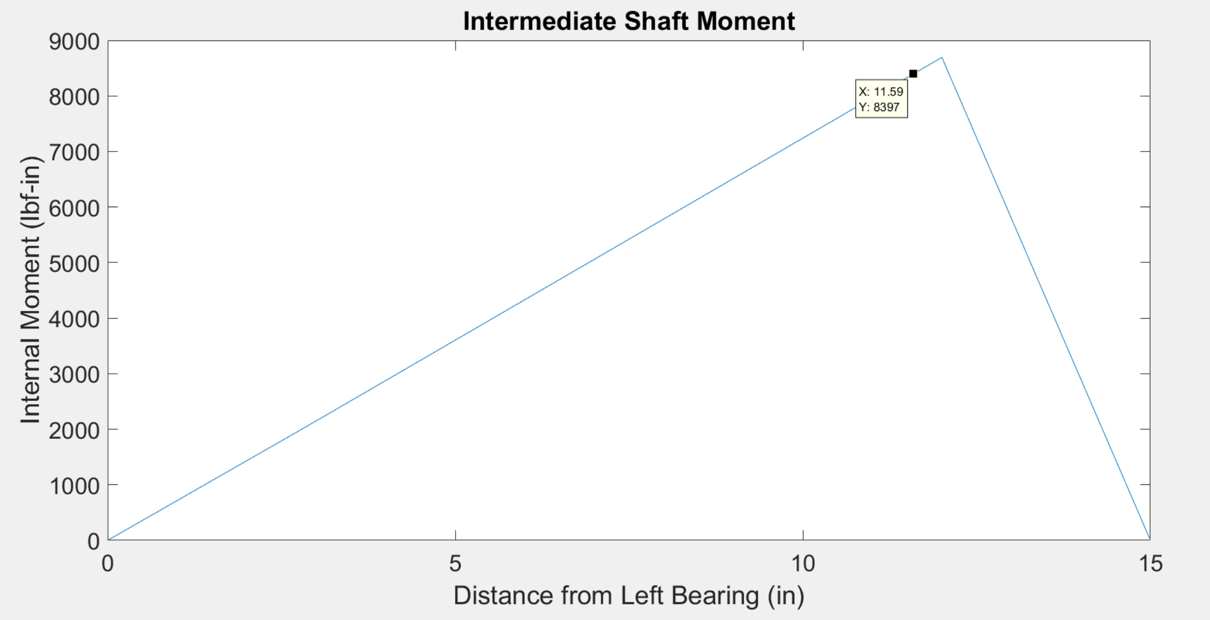
Intermediate Shaft

Yzplane

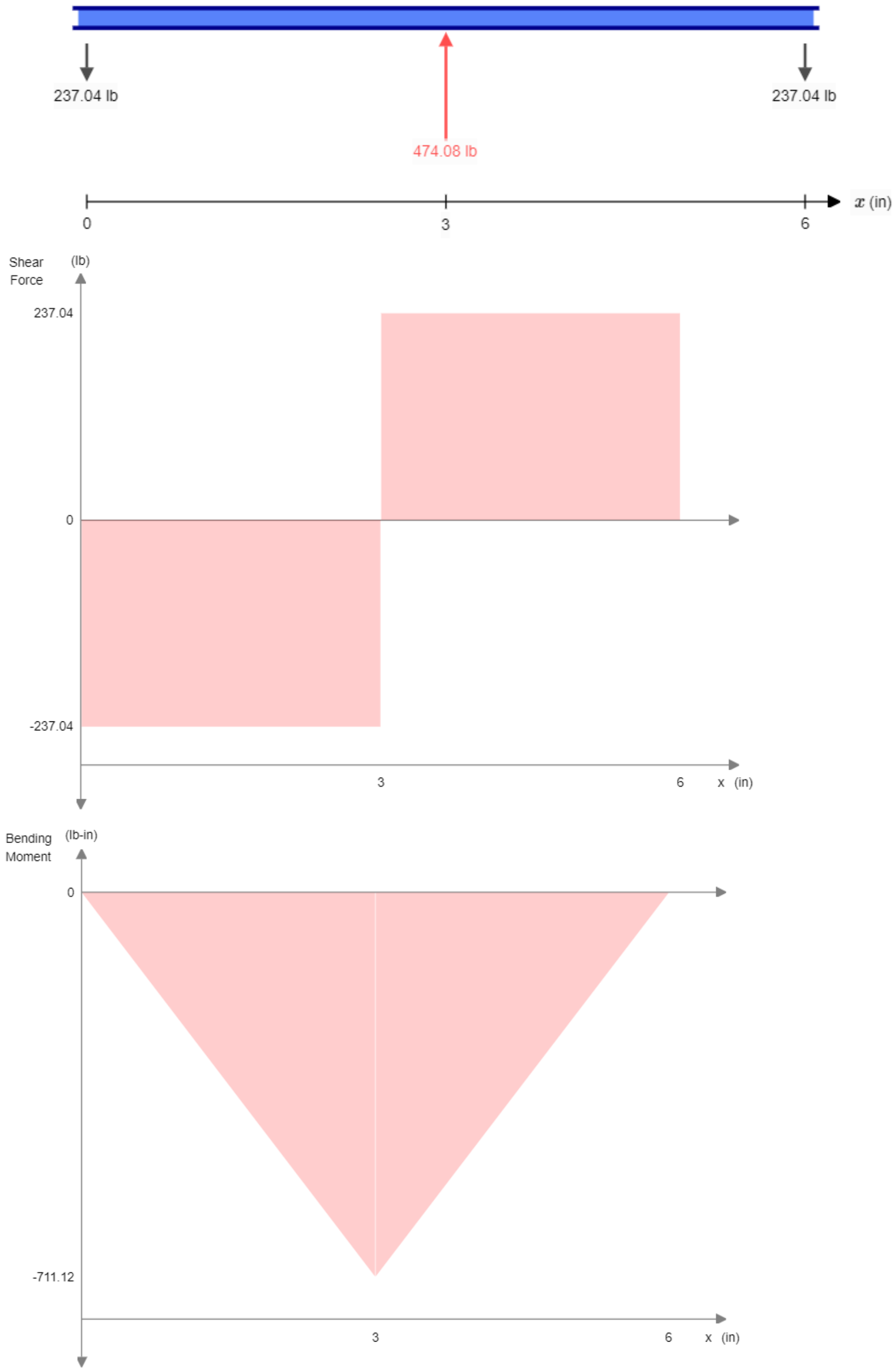


xy plane

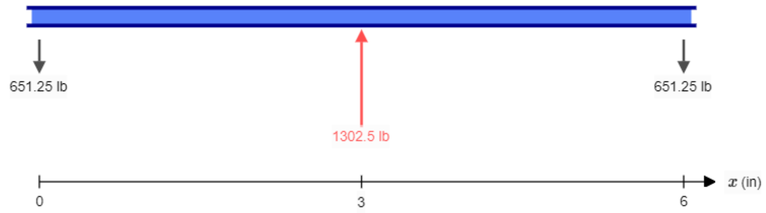

1302.5 lb
312.58 lb
2657.2 lb
3647.1 lb
0
3
12
15
x (in)
Shear Force (lb)
2657.18
312.58
0
-989.92
3
12
15
x (in)
Bending Moment (lb-in)
937.74
0
-7971.5
3
12
15
x (in)

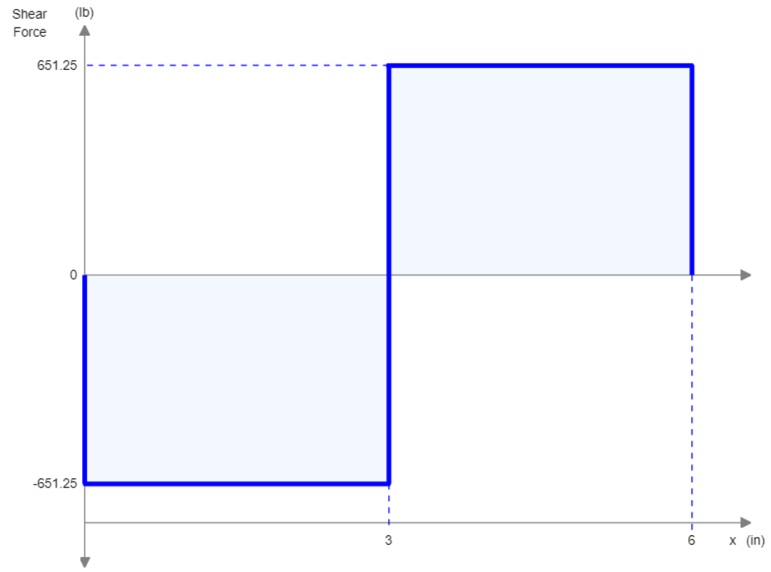

Intermediate Shaft Moment
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Internal Moment (lbf-in)
X: 11.59
Y: 8397
0
5
10
15
Distance from Left Bearing (in)

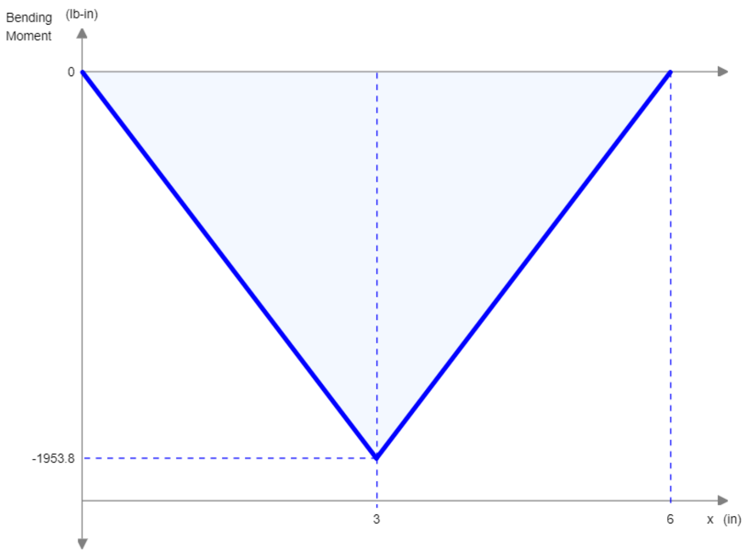
Input Shaft
yz plane

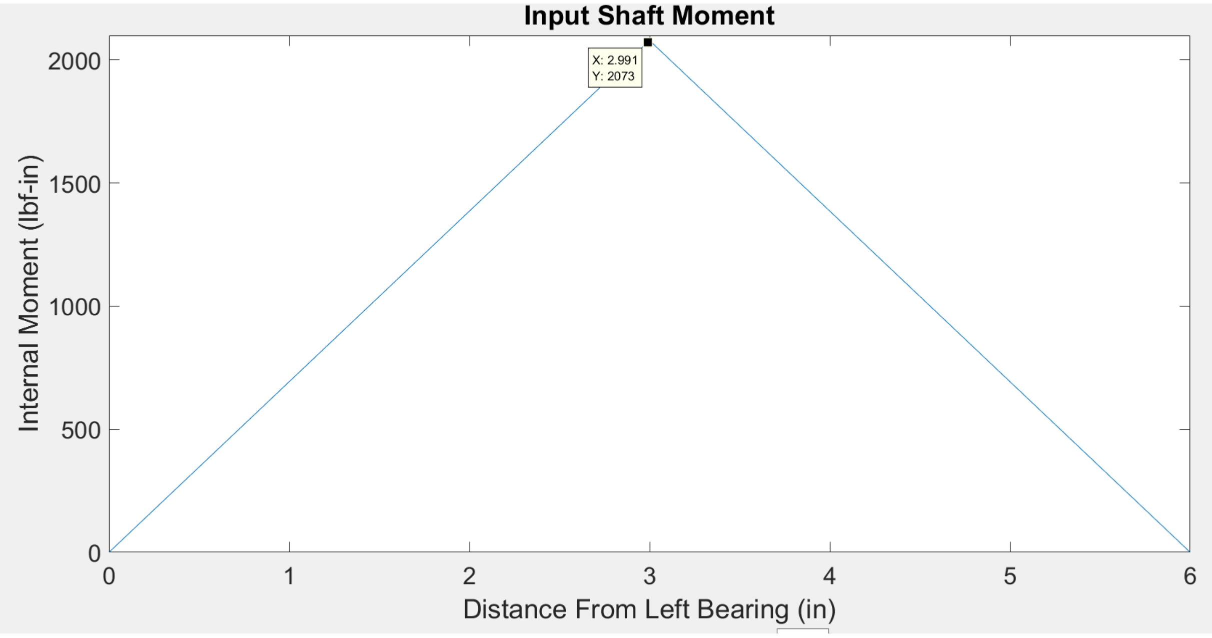


xy plane

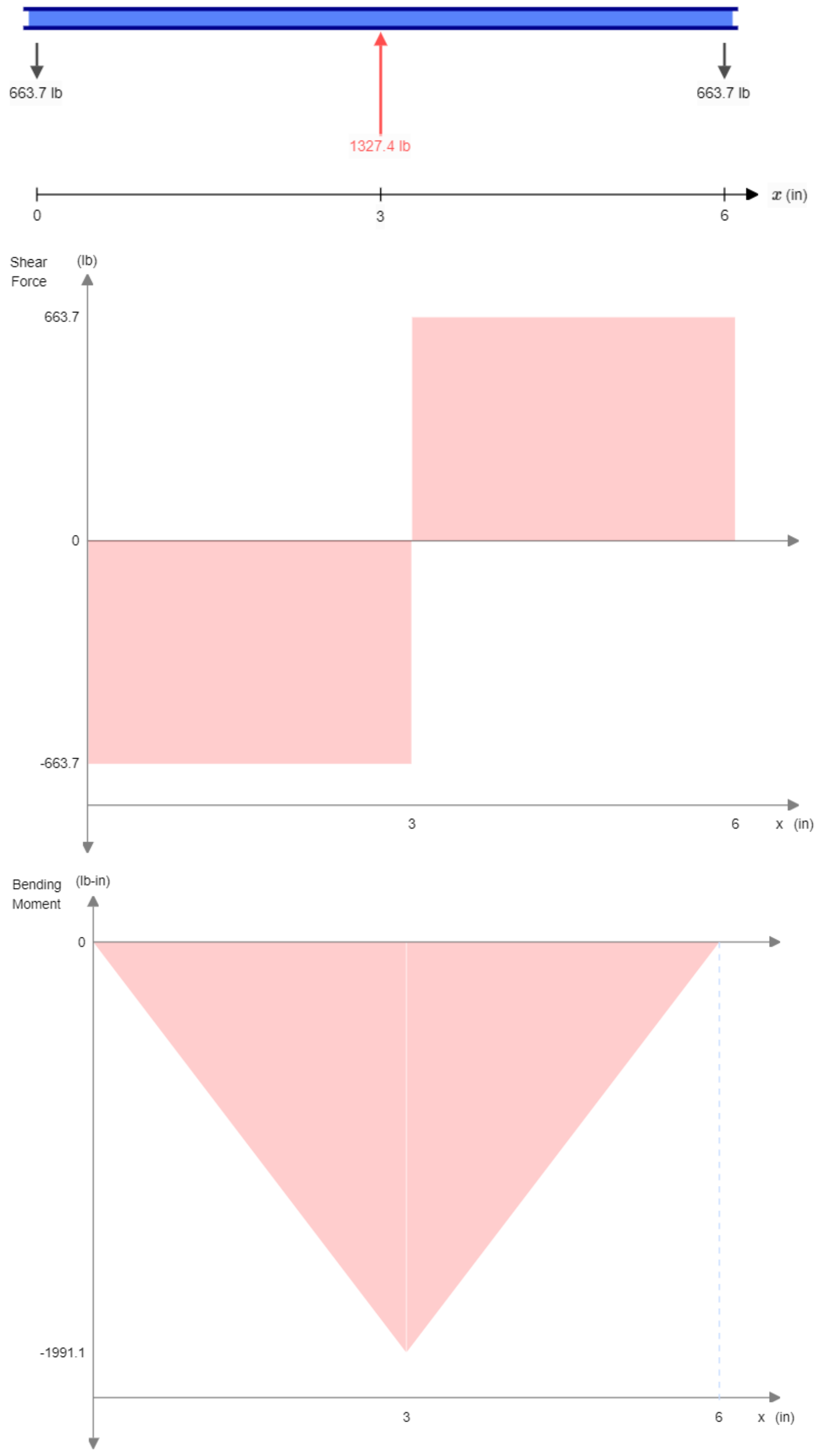

651.25 lb
651.25 lb
1302.5 lb
x (in)
0
3
6


Shear Force
(lb)
651.25
0
-651.25
3
6
x (in)

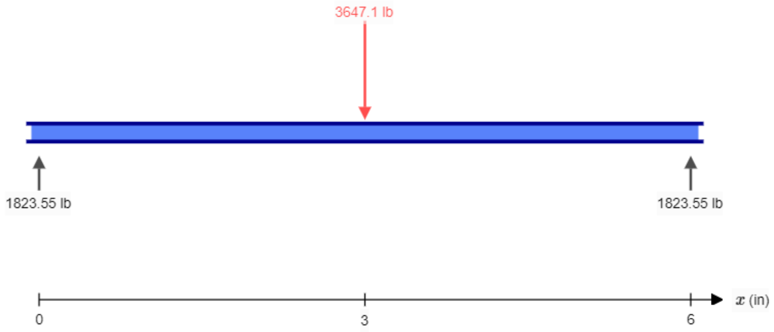

Bending Moment
(lb-in)
0
-1953.8
3
6
x (in)

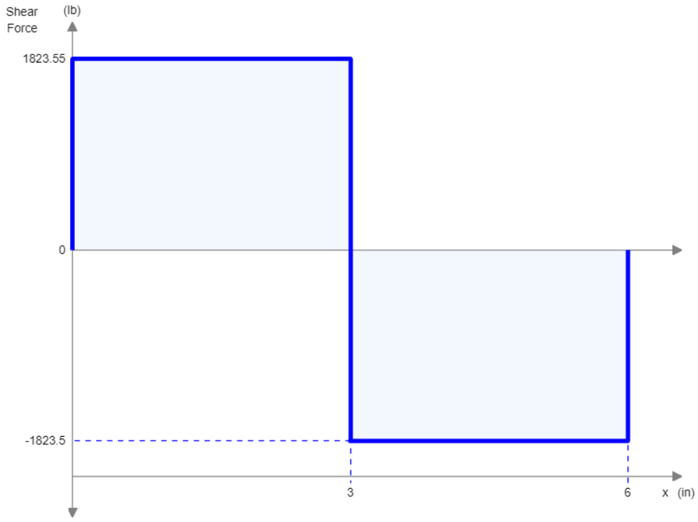

Input Shaft Moment
X: 2.991
Y: 2073
Internal Moment (lbf-in)
2000
1500
1000
500
0
0
1
2
3
4
5
6
Distance From Left Bearing (in)

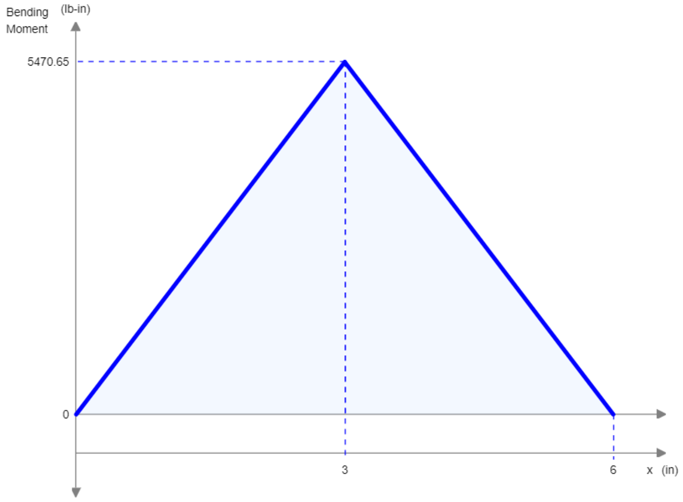
Output
yz plane

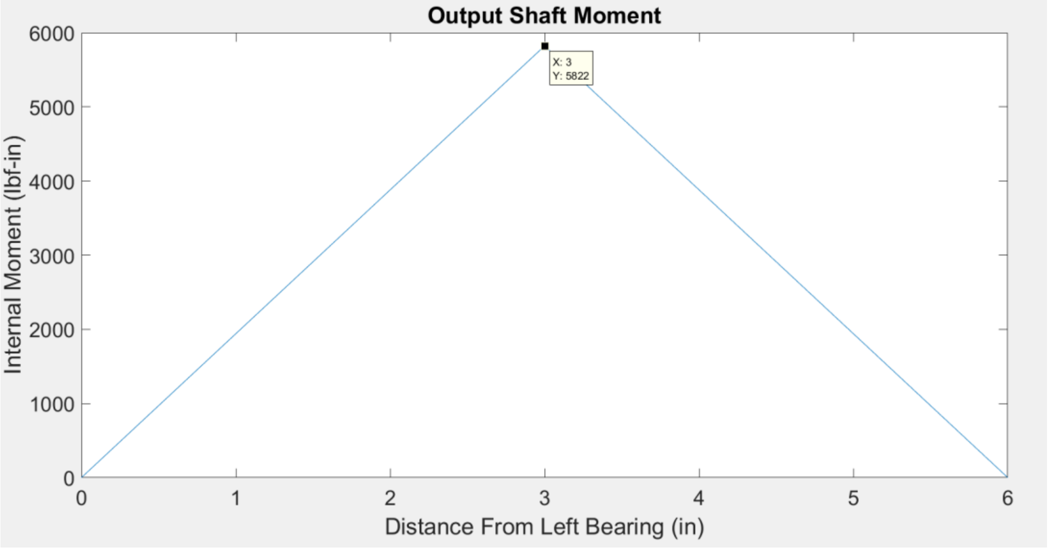


xy plane


3647.1 lb
1823.55 lb
1823.55 lb
0
3
6
x (in)


Shear Force
(lb)
1823.55
0
-1823.5
3
6
x (in)


Bending Moment
(lb-in)
5470.65
0
3
6
x (in)



5.3. Shaft force and stress calculation for all shafts

Please refer to attached MATLAB code.

5.4. Describe the FEM analysis and results

This section is concentrated on the analysis of the shafts with the help of SOLIDWORKS software. The shafts are inter connected with bearings and gears, these are major components when analyzing a shaft under stress. The objective is to model and simulate the bending and torsional forces acting on each shaft and test for, Von Mises stress and displacement of material. The results obtained by FEM indicate that the stress and displacements of the shafts and bearings are within boundary limits before failure (0.01 inch and 0.0008-0.0012 rad, respectively).

Input Shaft

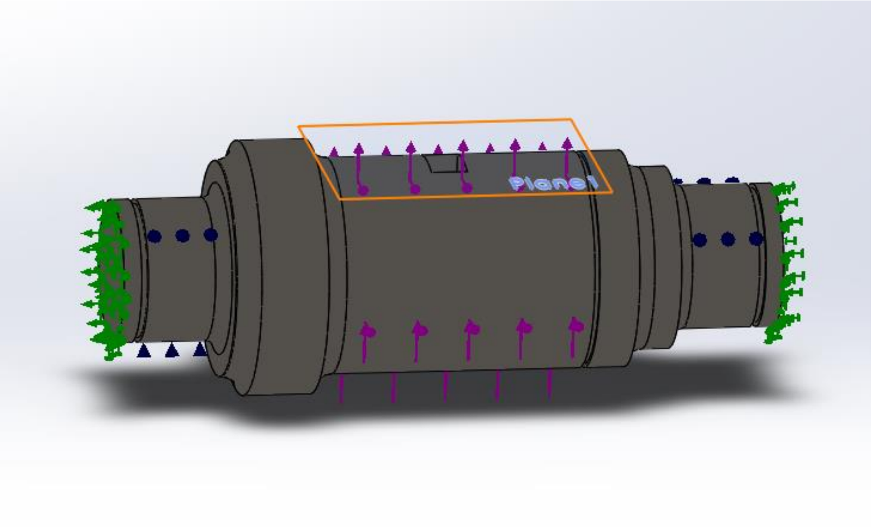


Figure 1: Force and boundary conditions on input shaft

FEM demonstrates the material displacement and the Von Mises stress distribution as shown below:

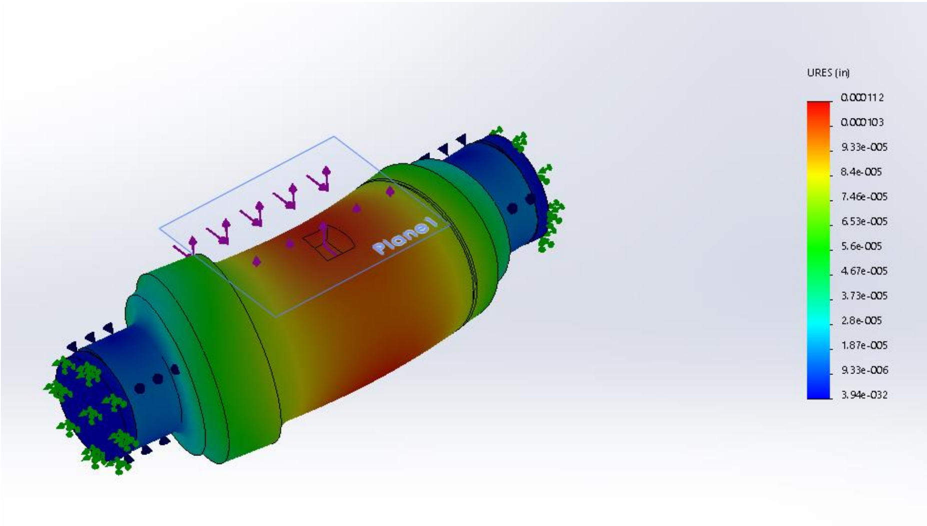


Figure 2: Resultant displacement of material in input shaft (inches)

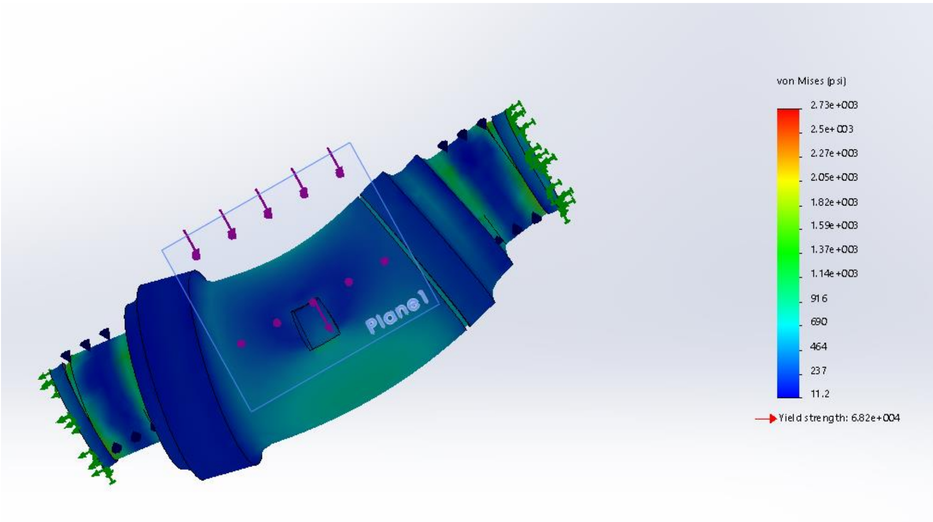


Figure 3: Von Mises stress (psi)

Displacement Plot:

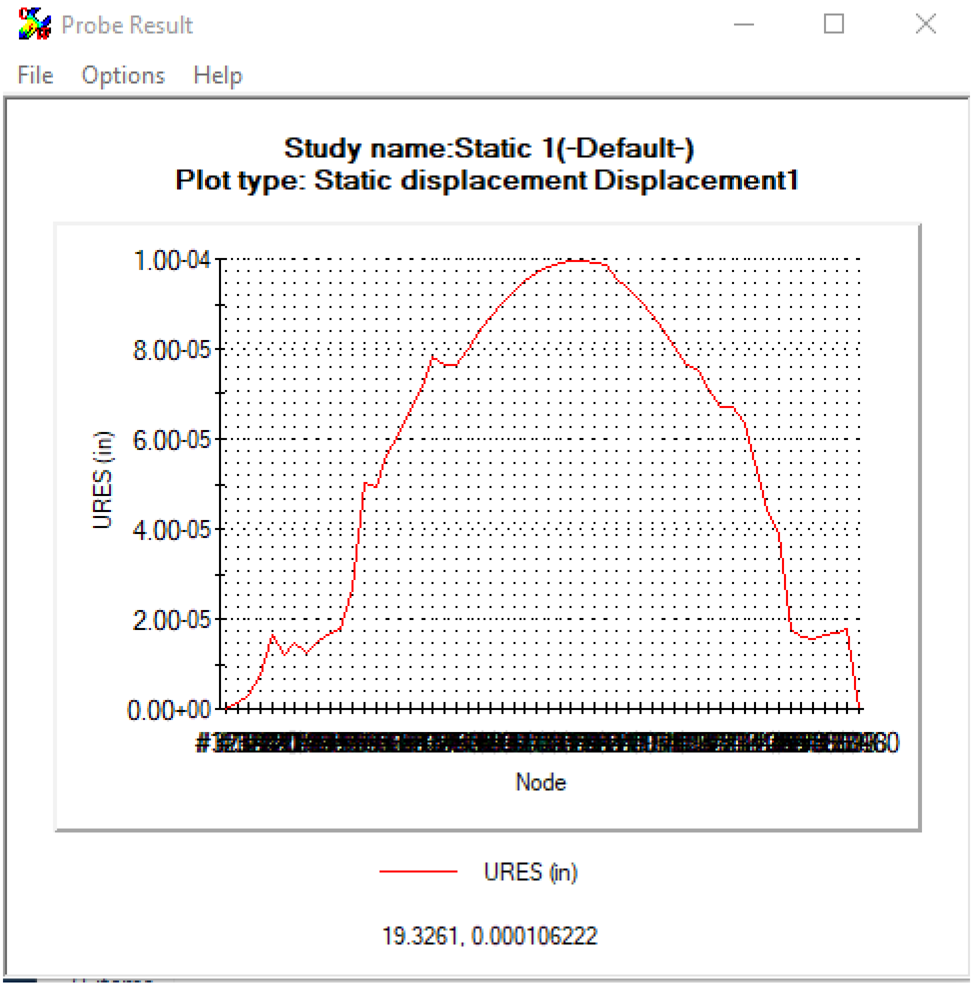


Figure 4: Displacement plot (in)

From the plot above, the displacement (in) are shown to be under the limits of failure, indicating the shaft material and design are appropriate for the input shaft.

Intermediate Shaft

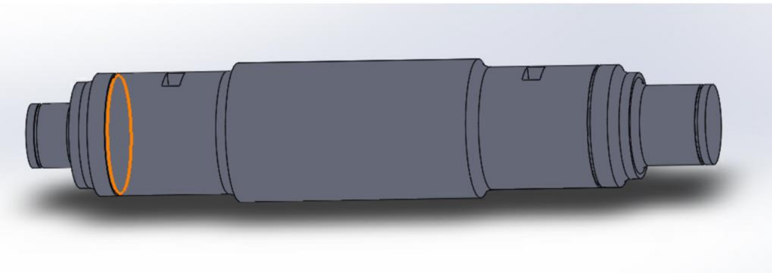


Figure 5: Output Shaft

FEM:

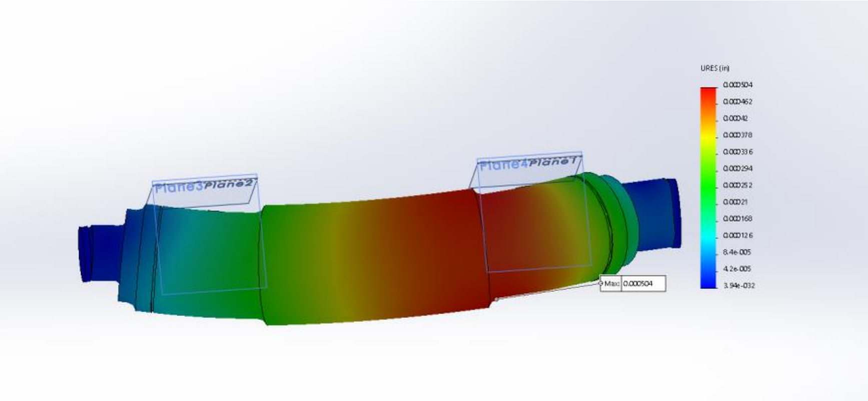


Figure 6: Resultant Displacement (in)

Von Mises:

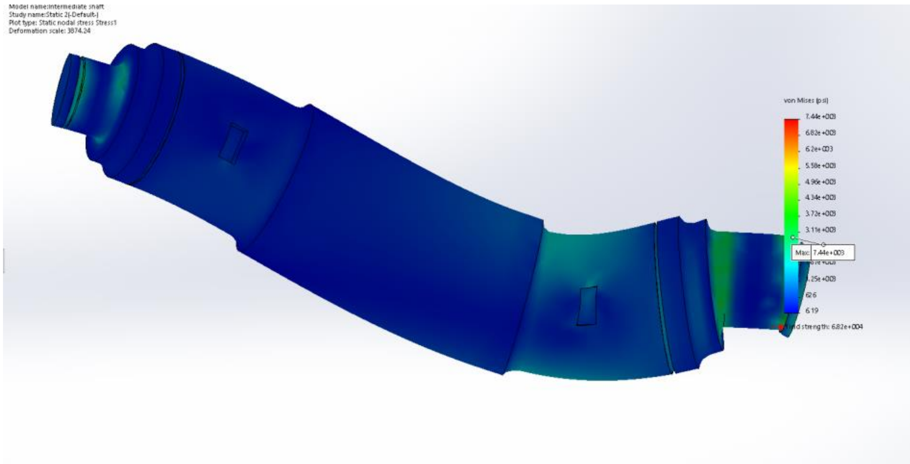


Figure 7: Von Mises Stress (psi)

From the FEM analysis, the displacement (in) are shown to be under the limits of failure, indicating the shaft material and design are appropriate for the intermediate shaft.

Output Shaft

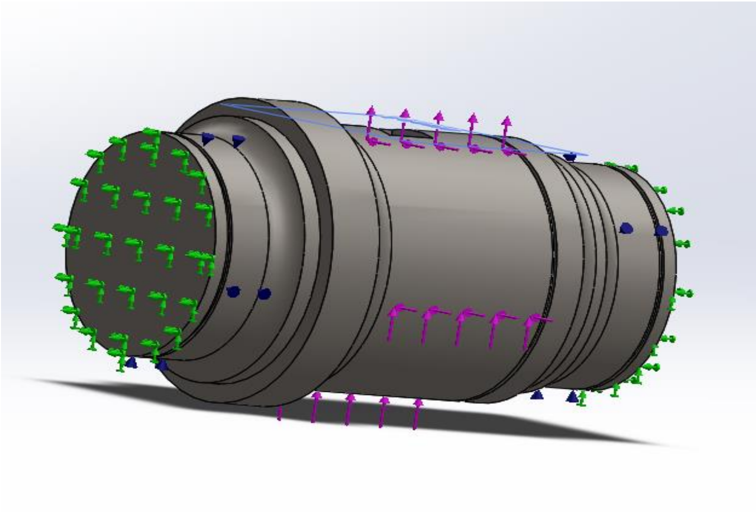


Figure 8: Force and boundary conditions on output shaft

FEM:

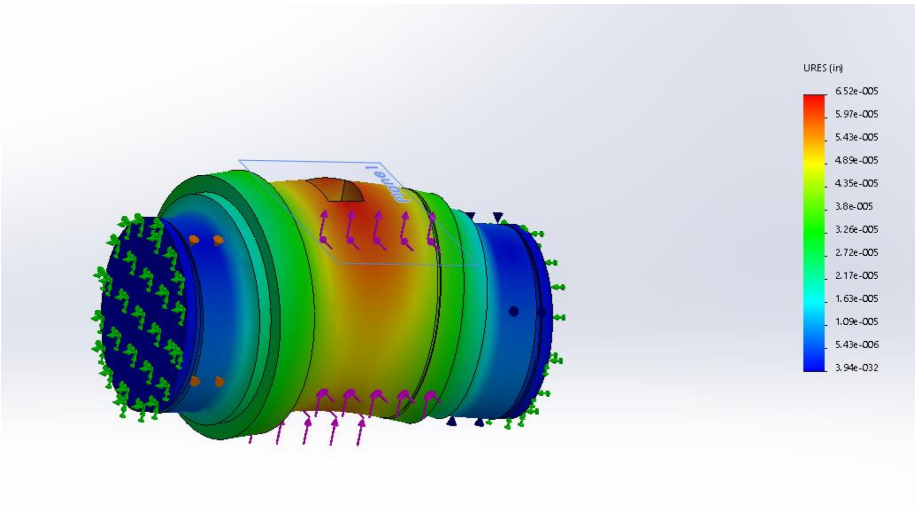


Figure 9: Resultant Displacement (in)

Displacement Plot:

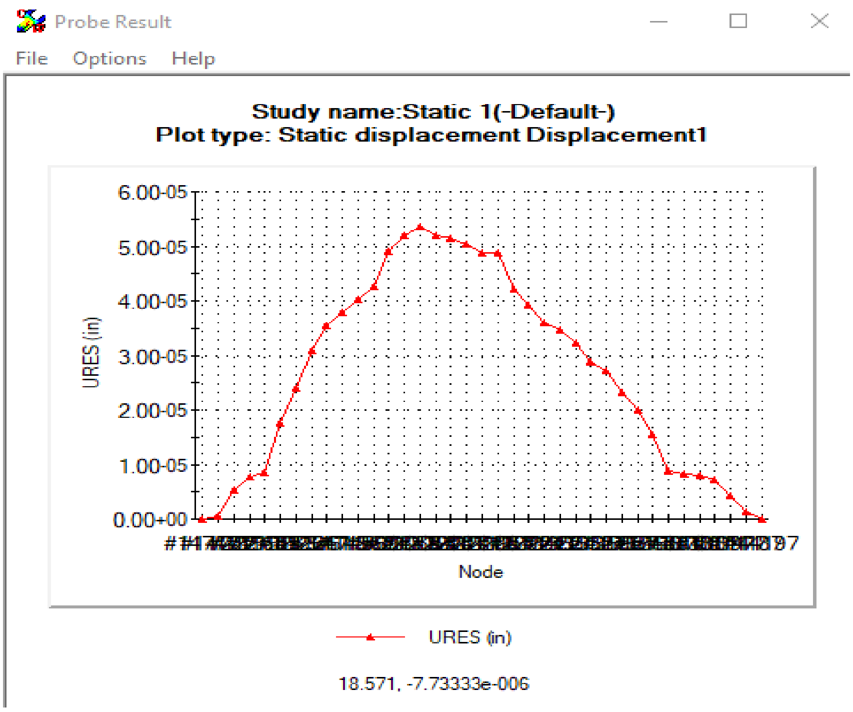


Figure 10: Displacement plot (in)

From the plot above, the displacement (in) are shown to be under the limits of failure, indicating the shaft material and design are appropriate for the output shaft.

5.5. Stress calculation for Key design

Please refer to attached hand written calculations.

Input shaft key

AISI 1045 CD steel shaft

62 hp

$n = 1300$ rpm

$d = 2.4 \quad r = 1.2$

$n_s = 1.5$

$$T = \frac{(63025)(62)}{1300} = 3005.807 \text{ lbf·in}$$

$$F = \frac{T}{r} = \frac{3006}{1.2} = 2505 \text{ lbf}$$

$$S_{sy} = 0.577(54) = 31.2 \text{ kpsi}$$

$$\frac{S_{sy}}{n_s} = \frac{31.2 \times 10^3}{1.5} = 20800 = \frac{F}{tL}$$

$w = \frac{5}{8} \quad h = \frac{5}{8}$

depth $= \frac{5}{16}$

$$20800 = \frac{2505}{.625L} \qquad L = 0.1926 \text{ in} \rightarrow 0.20 \text{ in}$$

$$\frac{S_y}{n_s} = \frac{F}{\frac{tL}{2}} \qquad \frac{6500L}{6500} = \frac{2505}{6500} = 0.3853 \rightarrow 0.40$$

Input shaft key

AISI 1045 CD steel shaft

62 hp

$n = 1300$ rpm

$d = 2.4 \quad r = 1.2$

$n_s = 1.5$

$$T = \frac{(63025)(62)}{1300} = 3005.807 \text{ lbf}\cdot\text{in}$$

$$F = \frac{T}{r} = \frac{3006}{1.2} = 2505 \text{ lbf}$$

$$S_{sy} = 0.577(54) = 31.2 \text{ kpsi}$$

$$\frac{S_{sy}}{n_s} = \frac{31.2\times10^3}{1.5} = 20800 = \frac{F}{tL}$$

$w = \frac{5}{8} \quad h = \frac{5}{8}$

depth $= \frac{5}{16}$

$$20800 = \frac{2505}{.625L} \qquad L = 0.1926\text{in} \rightarrow 0.20 \text{ in}$$

$$\frac{S_y}{n_s} = \frac{F}{\frac{tL}{2}} \qquad \frac{6500L}{6500} = \frac{2505}{6500} = 0.3853 \rightarrow 0.40$$

Output shaft key

$H = 62\ hp$ $d = 4.2$

$n = 155$ $r = 2.1$

$$T = \frac{63025(62)}{155} = 25210\ lbf \cdot in$$

$$F = \frac{25210}{2.1} = 12004.7619\ lbf$$

$S_y = 68167\ psi$

$S_{sy} = 0.577(54) = 31.158\ kpsi$

$W = 1$ $h = 1$

$$\frac{S_{sy}}{n} = \frac{F}{tl} = \frac{31.158}{1.5} = \frac{12004.7619}{(1)L} \quad L = 0.578 \rightarrow 0.6$$

$$\frac{S_y}{n} = \frac{F}{\frac{tL}{2}} \quad \frac{54\times10^3}{1.5} = \frac{12004.7619}{\frac{1}{2}L} \quad L = 0.6669 \rightarrow 0.7\ in$$

5.6. Bearing force calculation for all bearings

Please refer to attached MATLAB code.

5.7. Engineering drawings for all shafts with detailed dimensions

Input Shaft

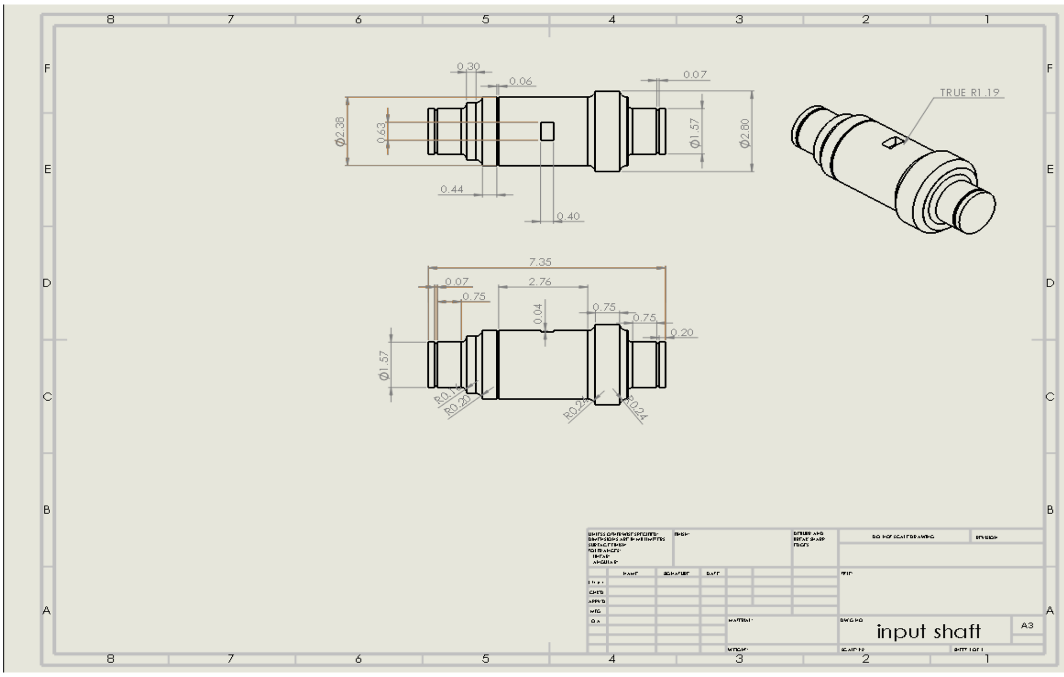


Figure 11: Input shaft Drawing

Intermediate Shaft

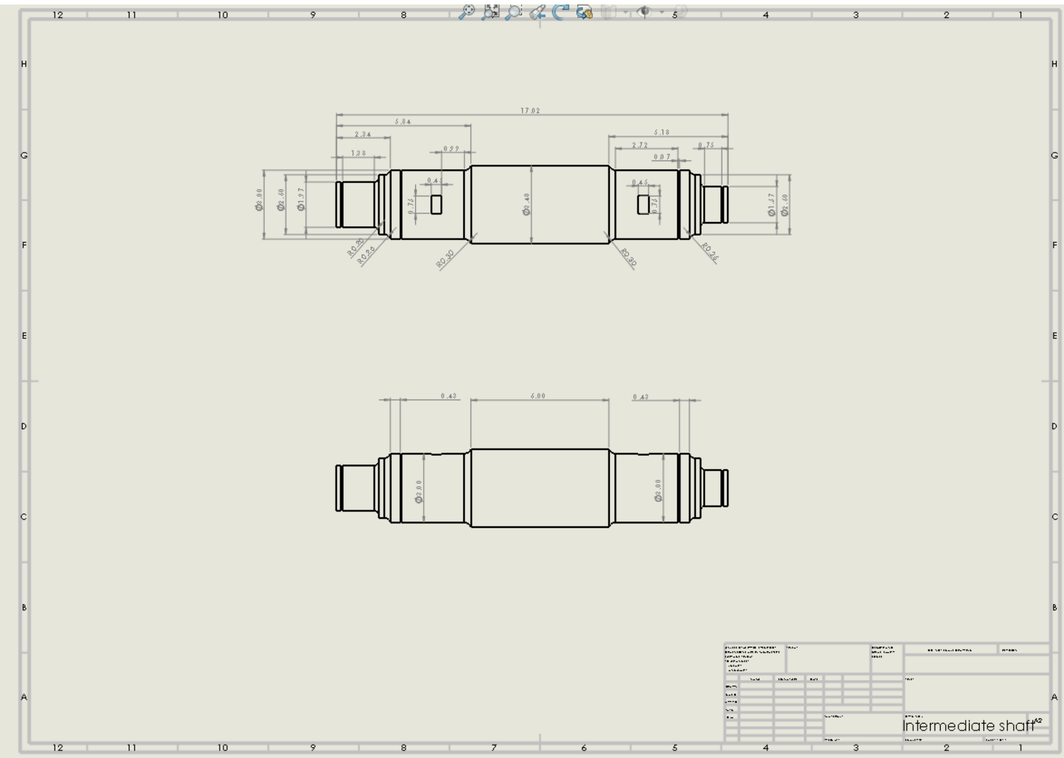


Figure 12: Intermediate shaft Drawing

Output Shaft

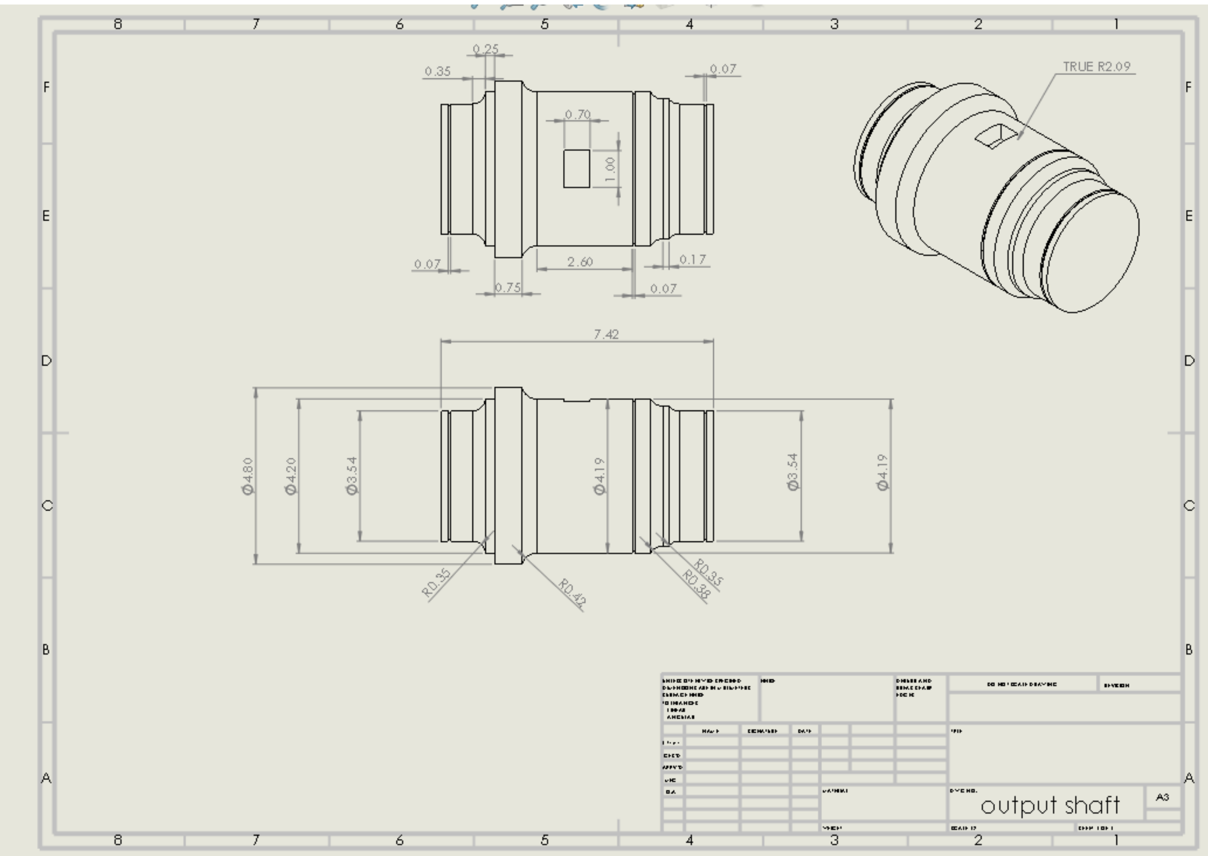


Figure 13: Output shaft Drawing

5.8. 3D CAD drawings of the assembled power transmission

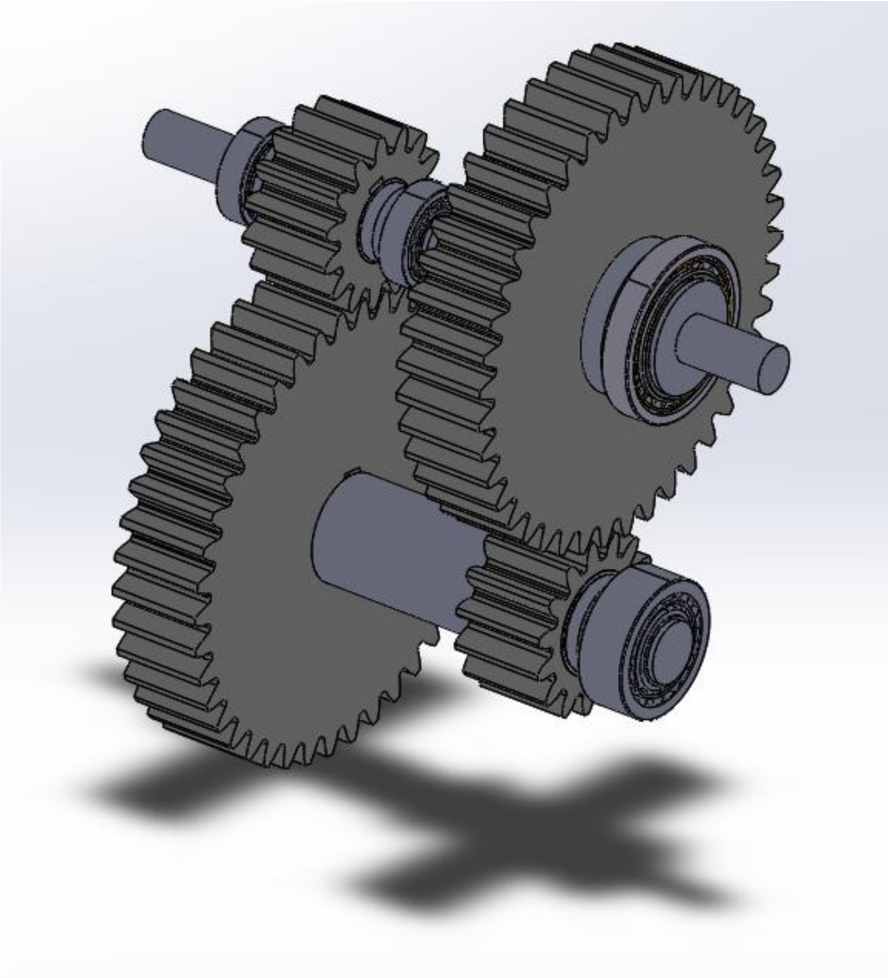


Figure 14: Assembled Power Transmission