Two Speed Portal Gearbox Design Project

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ME-541 Design II Fall 2017

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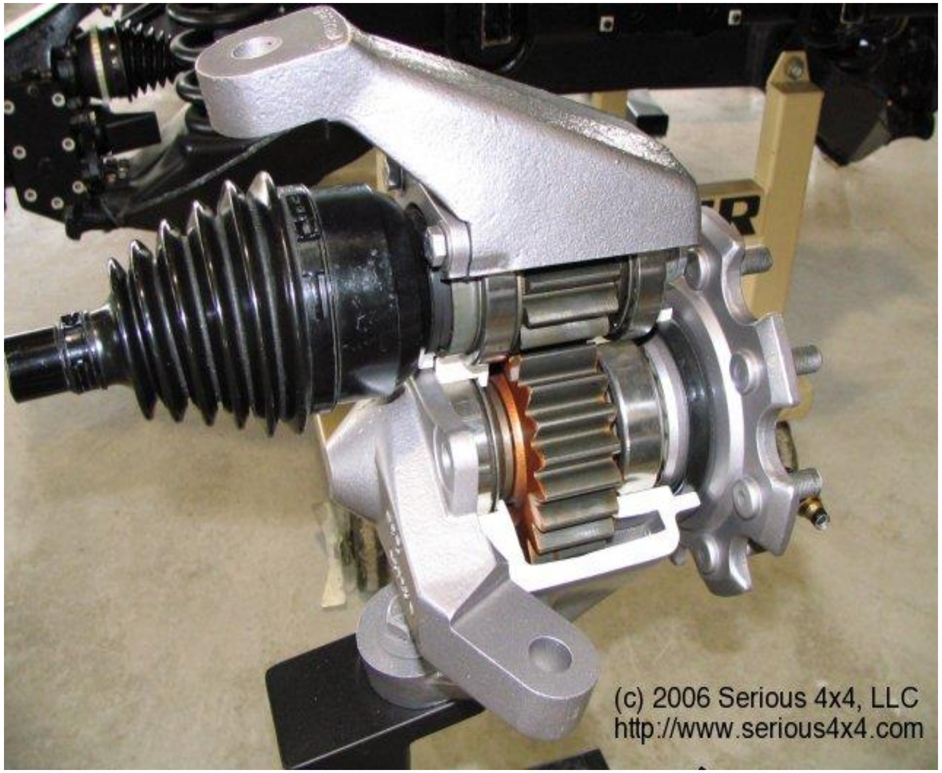
What is a 'Portal' Hub Gearbox and what does it do for vehicles?

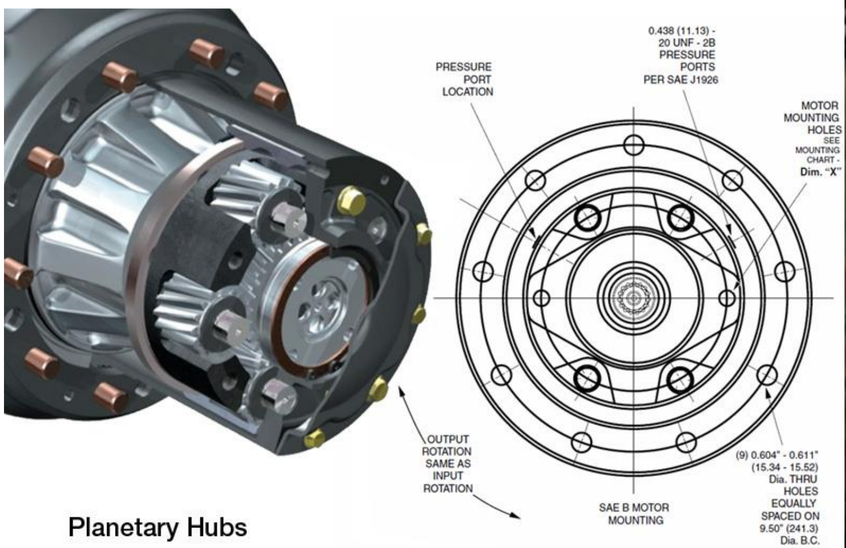
High mobility!

Portal hub application and layout

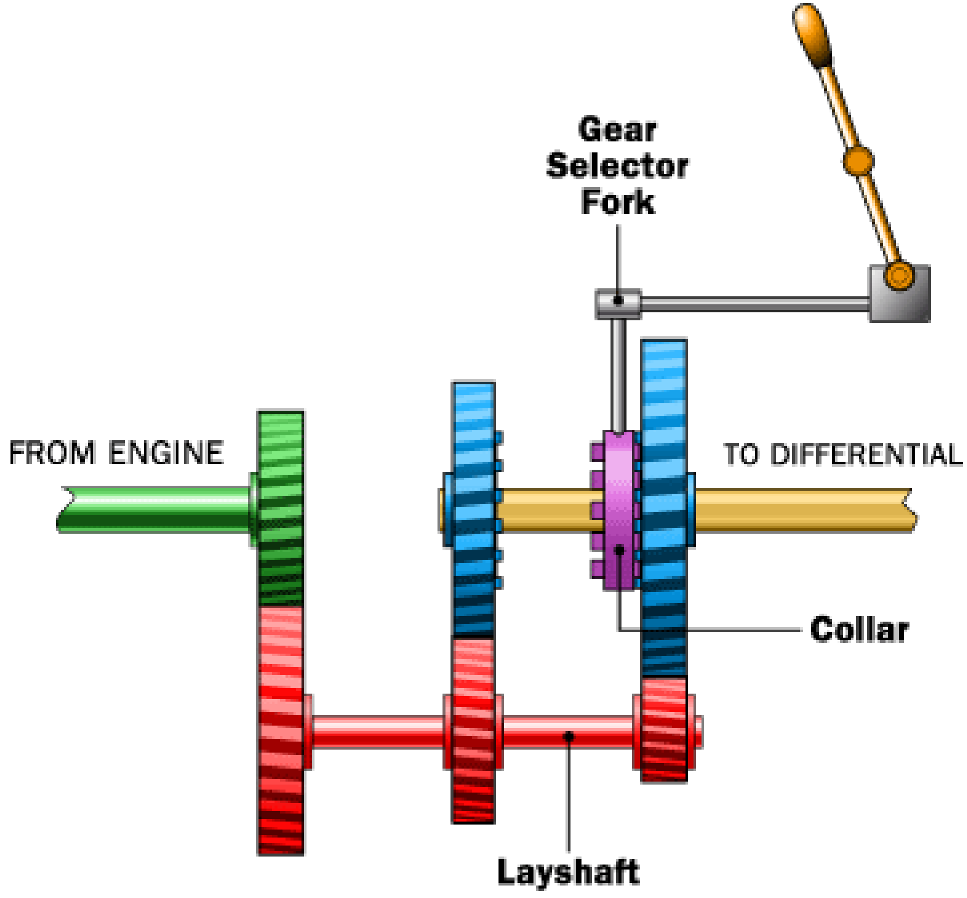
Alternate Existing designs.



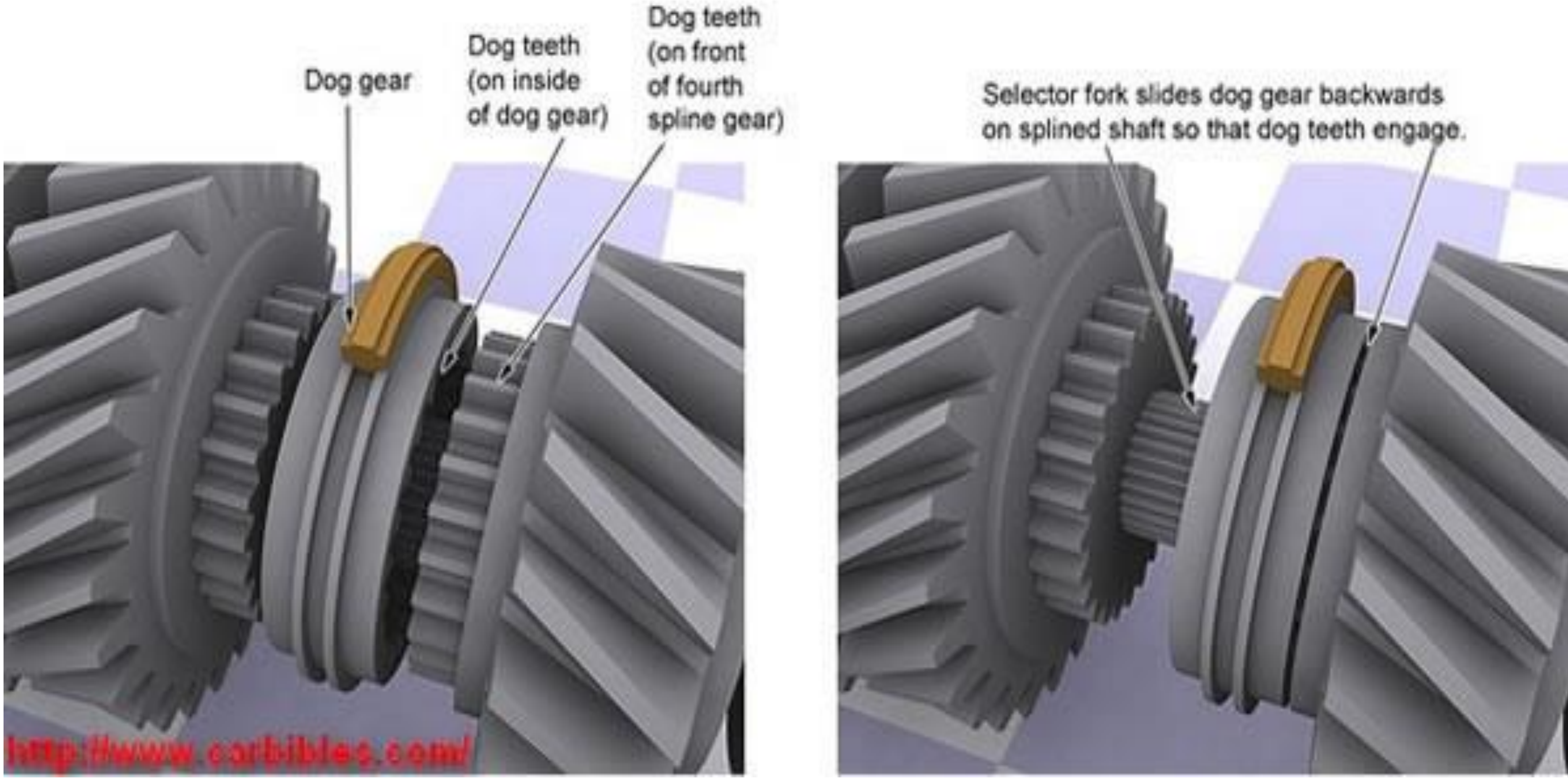
Alternate Existing Designs (cont)



Basic Principle of Operation



"Dog Clutch"


Dog gear
Dog teeth (on inside of dog gear)
Dog teeth (on front of fourth spline gear)
http://www.carbibles.com/
Selector fork slides dog gear backwards on splined shaft so that dog teeth engage.

Compiled Input Parameters

Total Input Power =	250	kW
Number of Gearboxes =	4	
Input Power to each Gearbox =	62.5	kW
Shaft Speed =	700	rpm
Gear Ratio 1 =	1	
Gear Ratio 2 =	2.75	
Arrangement =	Straight with Offset	
Application =	Heavy Equipment	
Drive =	Internal Combustion	
Housing =	Welding	
Desired Life =	10000.00	Hours

Assumptions

- Input power of 250 kW is divided into 4 separate gearboxes (62.5 kW each)
- Output speed desired to operate the vehicle at 70 mph, requires input speed ~700 rpm
- Gearcase will replace existing wheel bearing assy
- Spur gears used due to low shaft speeds
- Design life of 10,000 hours based on competitive gearboxes

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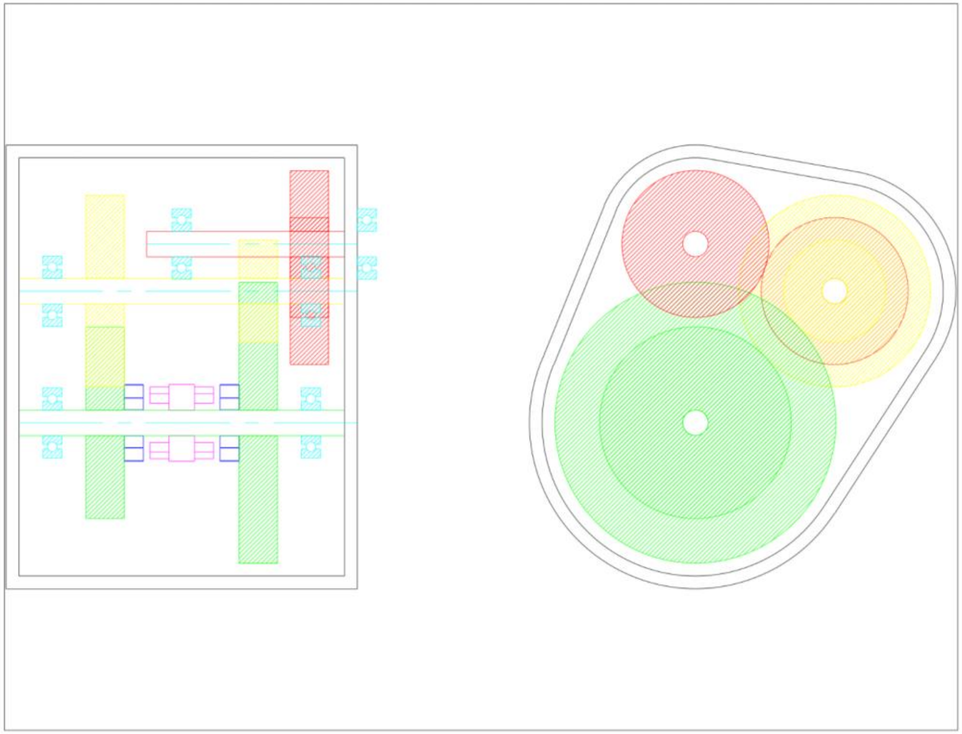
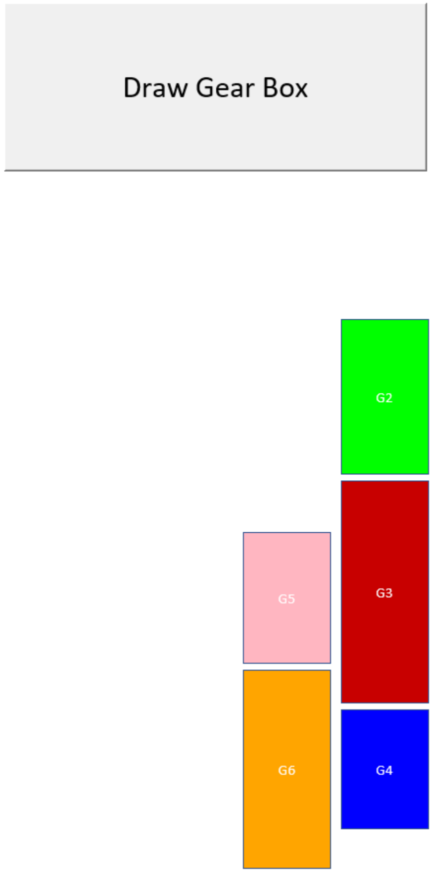
Geometry Layout

- Basic Portal Box layout with a customized offset
- Red = Input
- Yellow = Middle
- Green = Output



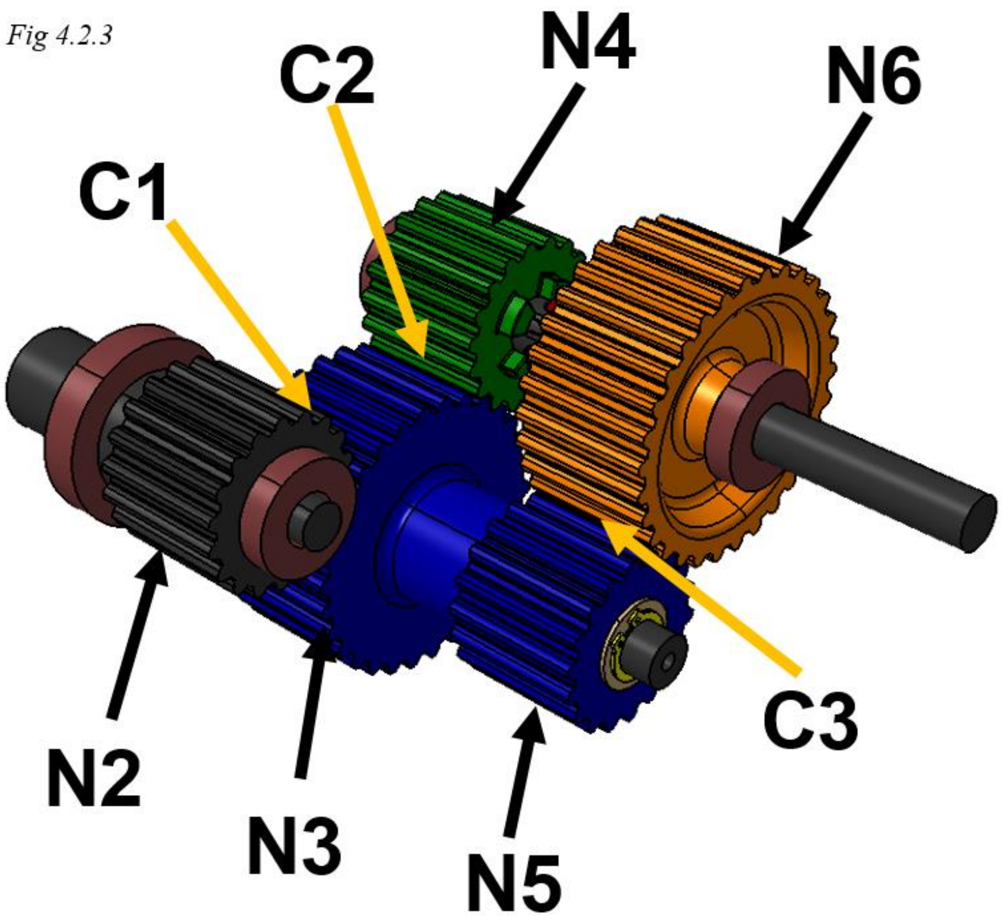
Geometry Layout – Cont.

- We designed a VBA function that created the layout of the gearbox for you in excel, for visual purposes



Geometry Layout – Cont.

Fig 4.2.3



Gear Dimensions

- Reduction per stage
  - Sqrt(2.75) = 1.658
- Minimum teeth on Pinion (14 teeth)
- Diameters and teeth counts maintain 1.658:1 ratio

- G2 = G4 = G5
  - 90 mm dia. 18 teeth
- G3 = G6
  - 150 mm dia. 30 teeth
- Face width 76.2 mm

	Gear 2				Gear 3			
Input Parameters	Pitch Diameter	d =	90.000	mm	Pitch Diameter	d =	149.220	mm
	Number of Teeth	N =	18.000	#	Number of Teeth	N =	29.844	#
	Pressure Angle	ϕ =	20.000	deg	Pressure Angle	ϕ =	20.000	deg
Calculated Parameters	Diametral Pitch	P =	0.200	mm	Diametral Pitch	P =	0.200	mm
	Module	m =	5.000	#	Module	m =	5.000	#
	Circular Pitch	p =	15.708	mm	Circular Pitch	p =	15.708	mm
	Addendum Diameter	a =	95.000	mm	Addendum Diameter	a =	154.220	mm
	Dedendum Diameter	b =	83.750	mm	Dedendum Diameter	b =	142.970	mm
	Clearance Diameter	c =	85.000	mm	Clearance Diameter	c =	144.220	mm
	Tooth Thickness	t =	7.854	mm	Tooth Thickness	t =	7.854	mm
	Base Pitch	p_b =	6.410	mm	Base Pitch	p_b =	6.410	mm

Diameter Selection Optimization

Diameter Selection

Gear Ratio (per stage)	1.658312395
kfull	1
kstub	0.8

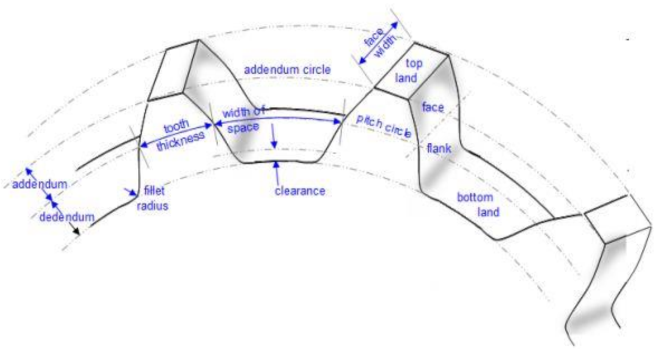
Pressure Angle	Np	Minimum Number of Teeth on Pinon (full)	p2stub	Np(stub)	Minimum Number of Teeth on Pinon (Stub)
20.000	13.714	14	3.462	10.971	11
20.100	13.589	14	3.464	10.871	11
20.200	13.465	14	3.465	10.772	11
20.300	13.344	14	3.467	10.675	11
20.400	13.224	14	3.468	10.579	11
20.500	13.106	14	3.469	10.485	11
20.600	12.990	13	3.471	10.392	11
20.700	12.875	13	3.472	10.300	11
20.800	12.762	13	3.473	10.210	11
20.900	12.650	13	3.475	10.120	11
21.000	12.541	13	3.476	10.033	11
21.100	12.432	13	3.477	9.946	10
21.200	12.326	13	3.479	9.861	10
21.300	12.220	13	3.480	9.776	10
21.400	12.117	13	3.482	9.693	10
21.500	12.014	13	3.483	9.611	10
21.600	11.913	12	3.485	9.531	10
21.700	11.814	12	3.486	9.451	10
21.800	11.716	12	3.487	9.373	10
21.900	11.619	12	3.489	9.295	10
22.000	11.523	12	3.490	9.219	10
22.100	11.429	12	3.492	9.143	10
22.200	11.336	12	3.493	9.069	10
22.300	11.245	12	3.494	8.996	9
22.400	11.154	12	3.496	8.923	9
22.500	11.065	12	3.497	8.852	9
22.600	10.977	11	3.499	8.781	9
22.700	10.890	11	3.500	8.712	9
22.800	10.804	11	3.502	8.643	9
22.900	10.720	11	3.503	8.576	9
23.000	10.636	11	3.505	8.509	9
23.100	10.553	11	3.506	8.443	9
23.200	10.472	11	3.508	8.378	9
23.300	10.392	11	3.509	8.313	9
23.400	10.312	11	3.511	8.250	9
23.500	10.234	11	3.512	8.187	9
23.600	10.157	11	3.514	8.125	9
23.700	10.080	11	3.515	8.064	9
23.800	10.005	11	3.517	8.004	9
23.900	9.930	10	3.518	7.944	8
24.000	9.857	10	3.520	7.886	8
24.100	9.784	10	3.521	7.827	8
24.200	9.713	10	3.523	7.770	8
24.300	9.642	10	3.524	7.713	8
24.400	9.572	10	3.526	7.657	8
24.500	9.503	10	3.527	7.602	8
24.600	9.434	10	3.529	7.548	8
24.700	9.367	10	3.530	7.494	8
24.800	9.300	10	3.532	7.440	8
24.900	9.235	10	3.533	7.388	8
25.000	9.170	10	3.535	7.336	8
25.100	9.105	10	3.536	7.284	8

Iteration #	Gear #	% error
1.000	1.658	17.08%
2.000	3.317	10.55%
3.000	4.975	0.50%
4.000	6.633	5.24%
5.000	8.292	3.64%
6.000	9.950	0.50%
7.000	11.608	3.27%
8.000	13.266	2.05%
9.000	14.925	0.50%
10.000	16.583	2.45%
11.000	18.241	1.34%
12.000	19.900	0.50%
13.000	21.558	2.01%
14.000	23.216	0.9408%
15.000	24.875	0.50%
16.000	26.533	1.73%
17.000	28.191	0.68%
18.000	29.850	0.50%
19.000	31.508	1.54%
20.000	33.166	0.50%
21.000	34.825	0.50%
22.000	36.483	1.34%
23.000	38.141	0.37%
24.000	39.799	0.50%
25.000	41.458	1.12%
26.000	43.116	0.27%
27.000	44.774	0.50%
28.000	46.433	0.9408%
29.000	48.091	0.19%
30.000	49.749	0.50%
31.000	51.408	0.80%
32.000	53.066	0.12%
33.000	54.724	0.50%
34.000	56.383	0.68%
35.000	58.041	0.07%
36.000	59.699	0.50%
37.000	61.358	0.59%
38.000	63.016	0.03%
39.000	64.674	0.50%
40.000	66.332	0.50%
41.000	67.991	0.01%
42.000	69.649	0.5013%
43.000	71.307	0.43%
44.000	72.966	0.05%
45.000	74.624	0.50%
46.000	76.282	0.37%
47.000	77.941	0.08%
48.000	79.599	0.50%
49.000	81.257	0.32%
50.000	82.916	0.10%
51.000	84.574	0.50%
52.000	86.232	0.27%

Lowest Error	0.00510%

Gear Design

- CAD models for the gears were generated as well
- A rim thickness was also added to reduce weight
- Extra teeth were added to Gear 4 and 6 for the clutch assembly



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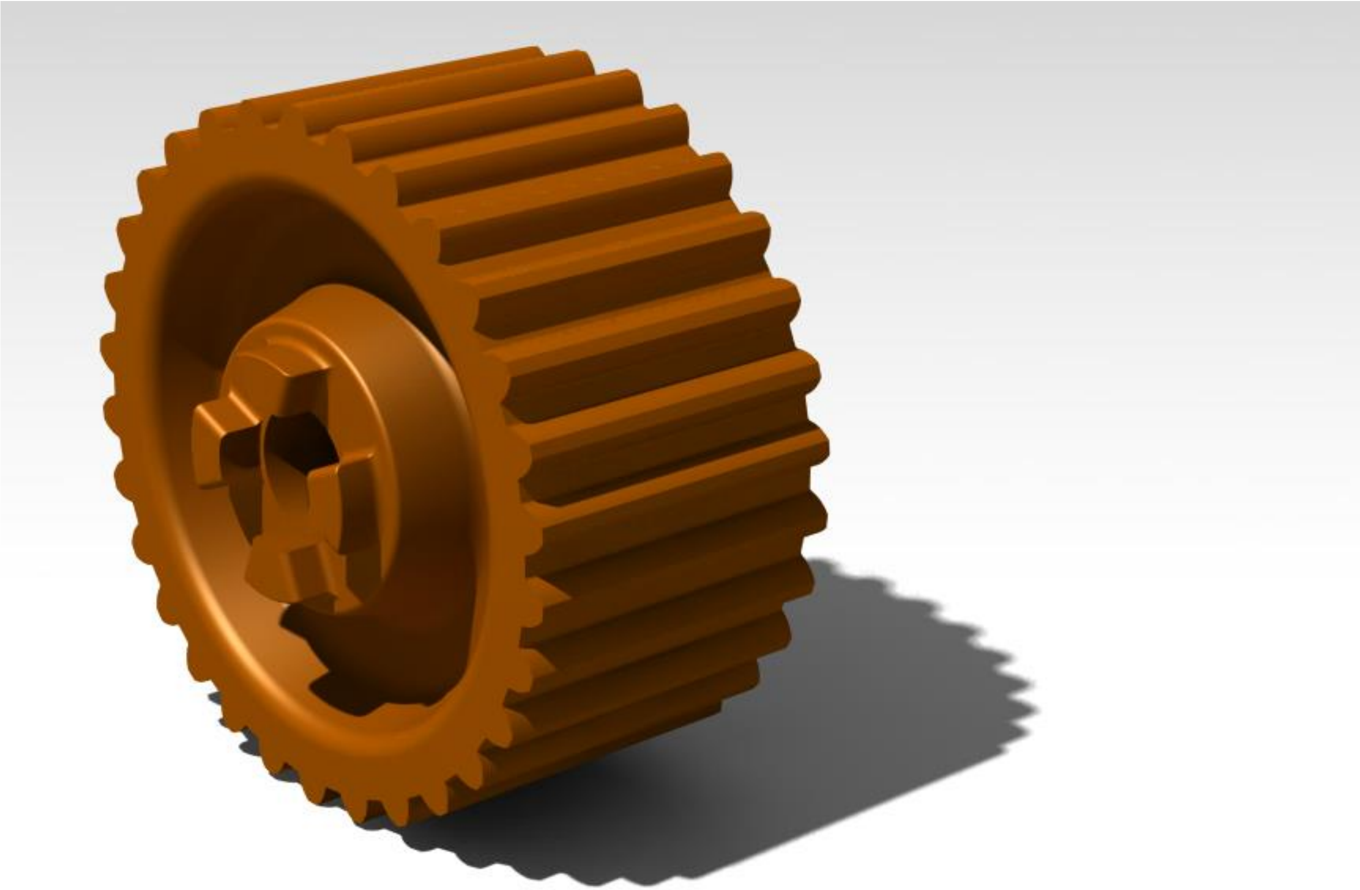
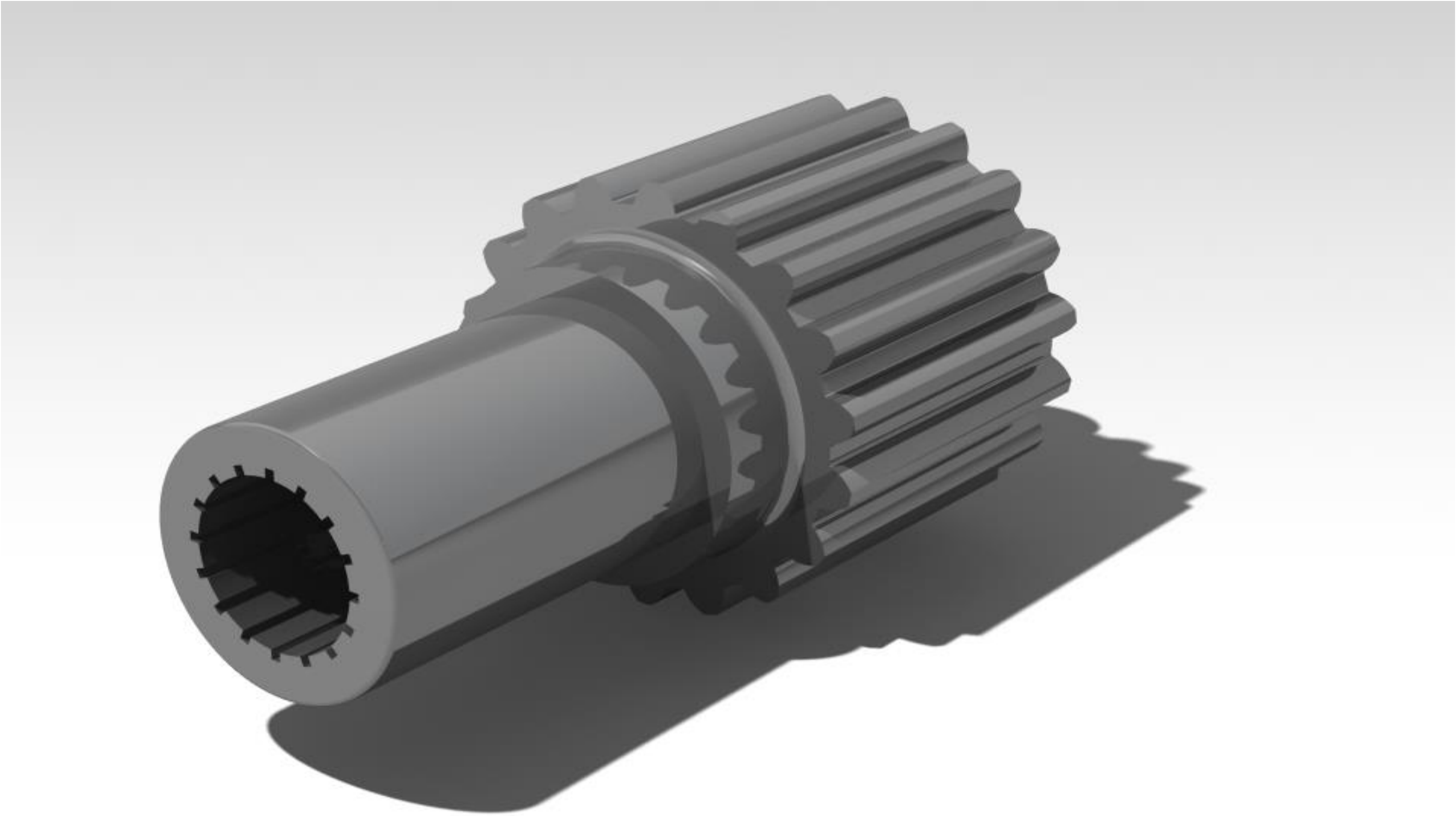
Gear Design – Cont.



Shaft Design - Input

- Integrated Gear
- Step to hold the outer bearing
- Splined attachment for axle input
- 25mm in diameter
- 51mm in diameter for the splined attachment

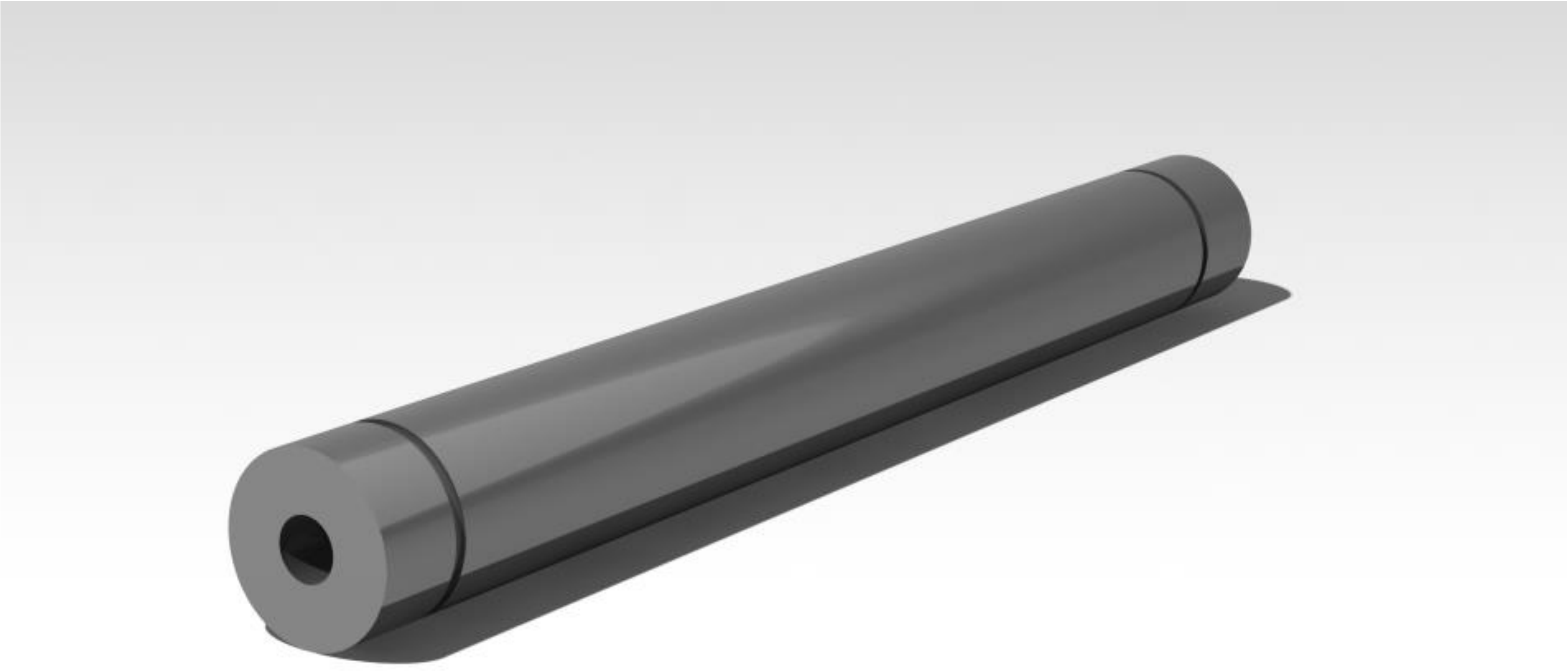
Shaft Design - Input



Shaft Design - Intermediate

- Solid shaft with 2 holes on the end
- 2 spots for snap rings
- No steps are needed
- Fixed Shaft

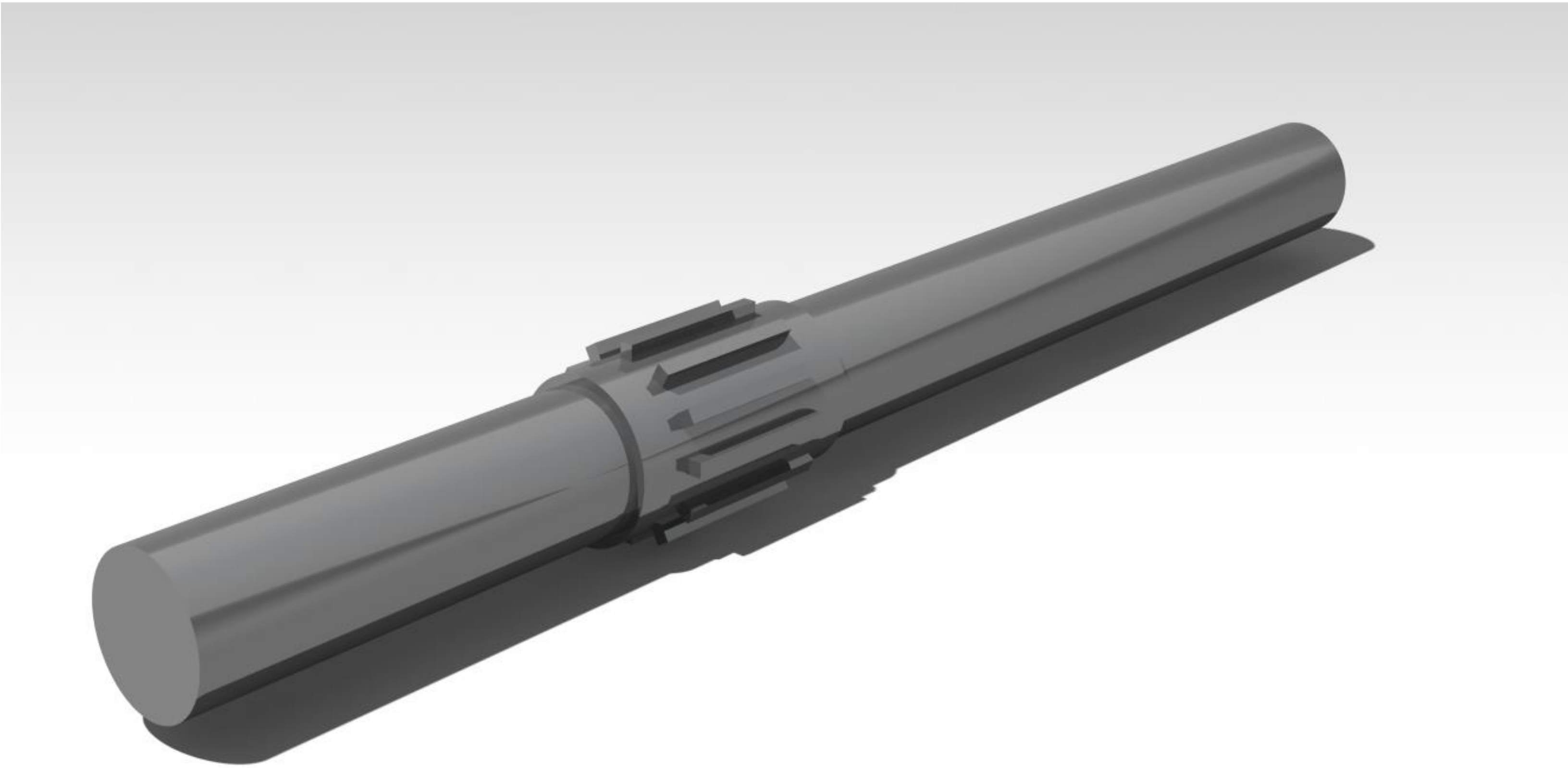
Shaft Design - Intermediate



Shaft Design - Output

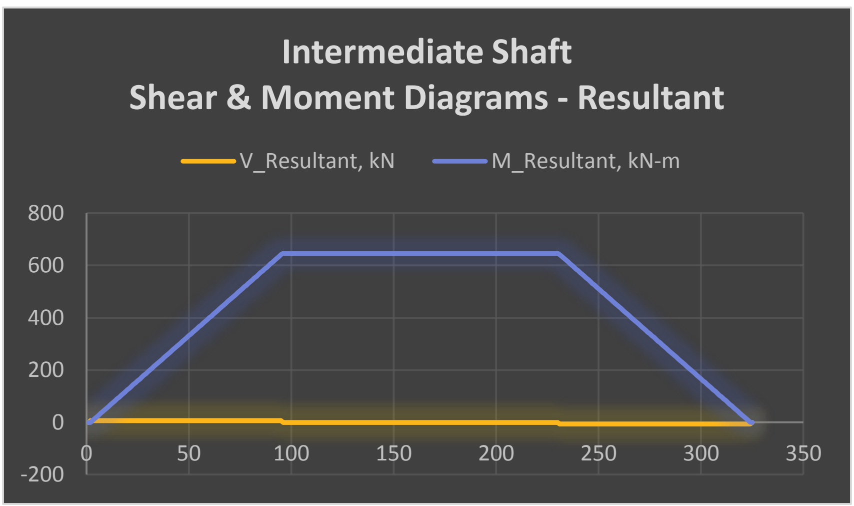
- 1 Step in the center
- Step contains male splines
- 25mm in diameter

Shaft Design - Output



Shear & Moment Diagrams

- Maximum shear & moment
  - Intermediate Shaft
  - Due to Shafts being offset

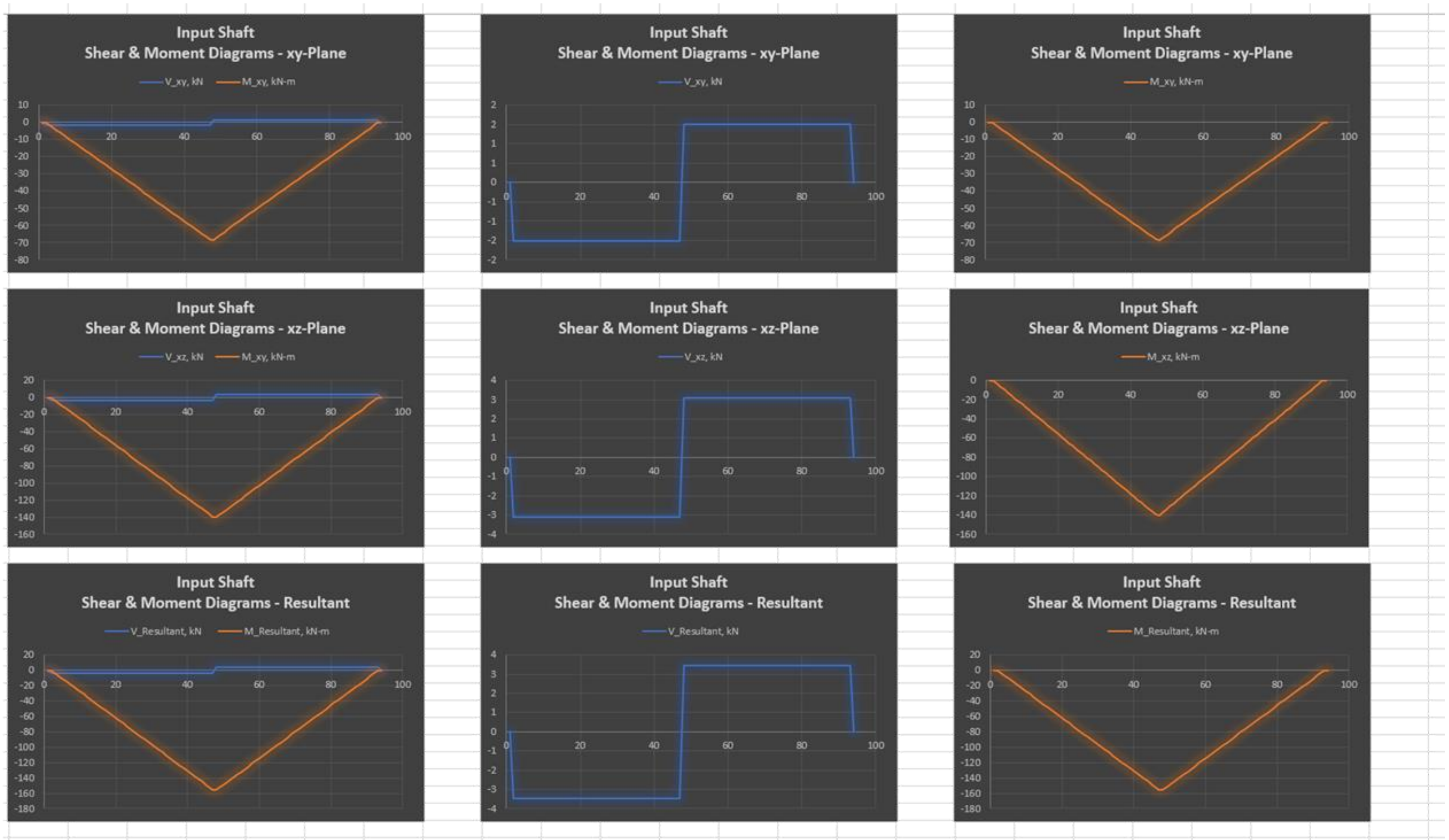


Intermediate Shaft

Tensile Strength	Sut =	570.000	Mpa
Yield Strength	Sy =	310.000	Mpa
Endurance Limit Estimate	Se' =	285.000	Mpa
Surface Correction Factor			
Factor A	a =	4.510	
Exponent B	b=	-0.265	
Surface Factor	Ka =	0.839	
Size Correction Factor			
Diameter	d =	4.691	mm
Effective Diameter	de =	1.736	mm
Size Factor	Kb =	1.137	
Loading Correction Factor			
Bending	kc	1.000	
Axial	kc	0.850	
Torsion	kc	0.590	
Loading Factor	Kc	1.000	
Temperature Correction Factor			
Temperature	Tf =	500.000	C
	Tf =	260.000	F
	Kd =	1.025	
Reliability Correction Factor			
Reliability	R =	99	%
	Ke =	0.814	
Corrected Endurance Limit			
Endurance Limit	Se =	226.959	Mpa

Maximum Moment	M =	646.859	kN-m	
Reversed Stress	σrev =	6589 /d^3	Kpa	$\sigma_{rev} = \frac{32M}{\pi d^3}$
D/d Ratio	D/d =	1.250		
r/d Ratio	r/d =	0.100		
Stress Concentration	Kt =	1.700		Figure A-15-9
Shear Stress Concentration	Kts =	1.500		Figure A-15-8
Notch Factor	q =	0.850		ESTIMATE
Shear Notch Factor	qs =	0.850		ESTIMATE
Fatigue Stress Concentration	Kf =	1.595		$K_f = 1 + q(K_t - 1)$
Fatigure Shear Stress	Kfs =	1.425		
ESTIMATES				
Surface Factor	Ka =	0.839		
Size Factor	Kb =	1.078		From Table Below
Loading Factor	Kc =	1.000		
Temperature Factor	Kd =	1.000		
Reliability Factor	Ke =	1.000		
Endurance Limit	Se =	257.868	Mpa	$S_e = k_a k_b k_c k_d k_e S_e'$
Stress Calculation				
Fatigue Strength Fraction	f =	0.870		Figure 6-18
	a =	953.652		$a = \frac{(fS_{ut})^2}{S_e}$
	b =	-0.095		$b = -\frac{1}{3}\log\left(\frac{fS_{ut}}{S_e}\right)$
Desired Life	L =	10000.000	Hours	
Shaft Speed at Stage 1	n1 =	422.195	rpm	
Shaft Speed at Stage 2	n2 =	422.195	rpm	
Number of Cycles at Stage 1	N1 =	2.53E+08	Cycles	
Number of Cycles at Stage 2	N2 =	2.53E+08	Cycles	
Fatigue Strength at Stage 1	Sf1 =	152.705	Mpa	$S_f = aN^b$
Fatigue Strength at Stage 2	Sf2 =	152.705	Mpa	
Factor of Safety	n =	1.500		$n_f = \frac{S_f}{K_f \sigma_{rev}}$
Minimum Diameter	d =	4.691	mm	
Recalculation				
Effective Diameter	de =	1.736		
Size Factor	Kb =	1.2200		

Shear & Moment Diagrams



Optimization for Kb Values

- The iteration table will search for values that equal, highlight them and input them into the usable table

Iterations To Find Corrected Kb

Kbo	Se	a	b	Sf	d	de	.	Kb
0.1000	12.66	19428.05	-0.53	0.51	29.13	10.78		0.8537
0.1100	13.92	17661.86	-0.52	0.61	27.45	10.16		0.8617
0.1200	15.19	16190.04	-0.50	0.72	25.99	9.62		0.8691
0.1300	16.46	14944.65	-0.49	0.84	24.73	9.15		0.8760
0.1400	17.72	13877.18	-0.48	0.96	23.61	8.73		0.8824
0.1500	18.99	12952.03	-0.47	1.10	22.61	8.37		0.8883
0.1600	20.25	12142.53	-0.46	1.24	21.72	8.04		0.8940
0.1700	21.52	11428.26	-0.45	1.38	20.91	7.74		0.8993
0.1800	22.78	10793.36	-0.45	1.54	20.18	7.47		0.9044
0.1900	24.05	10225.29	-0.44	1.71	19.51	7.22		0.9092
0.2000	25.32	9714.02	-0.43	1.88	18.89	6.99		0.9138
0.2100	26.58	9251.45	-0.42	2.06	18.32	6.78		0.9182
0.2200	27.85	8830.93	-0.42	2.25	17.80	6.59		0.9224
0.2300	29.11	8446.98	-0.41	2.44	17.31	6.41		0.9264
0.2400	30.38	8095.02	-0.40	2.64	16.86	6.24		0.9303
0.2500	31.64	7771.22	-0.40	2.85	16.43	6.08		0.9340
1.0600	134.17	1832.83	-0.19	42.78	6.66	2.47		1.0762
1.0700	135.44	1815.71	-0.19	43.54	6.63	2.45		1.0772
1.0800	136.70	1798.89	-0.19	44.30	6.59	2.44	X	1.0782
1.0900	137.97	1782.39	-0.19	45.08	6.55	2.42		1.0791
1.1000	139.24	1766.19	-0.18	45.85	6.51	2.41		1.0801
1.1100	140.50	1750.27	-0.18	46.64	6.47	2.40		1.0811

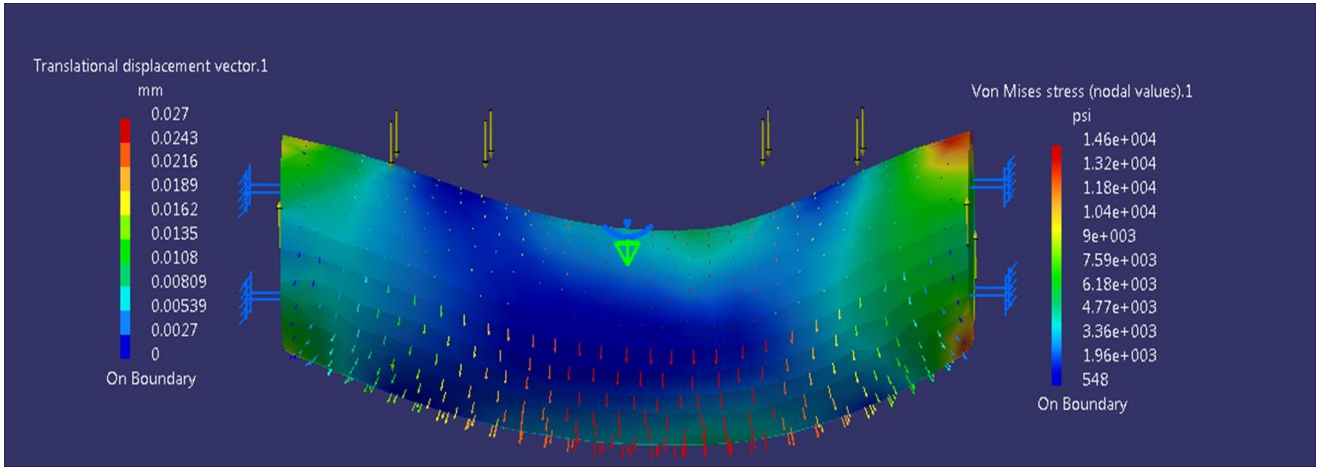
Bearing Selection

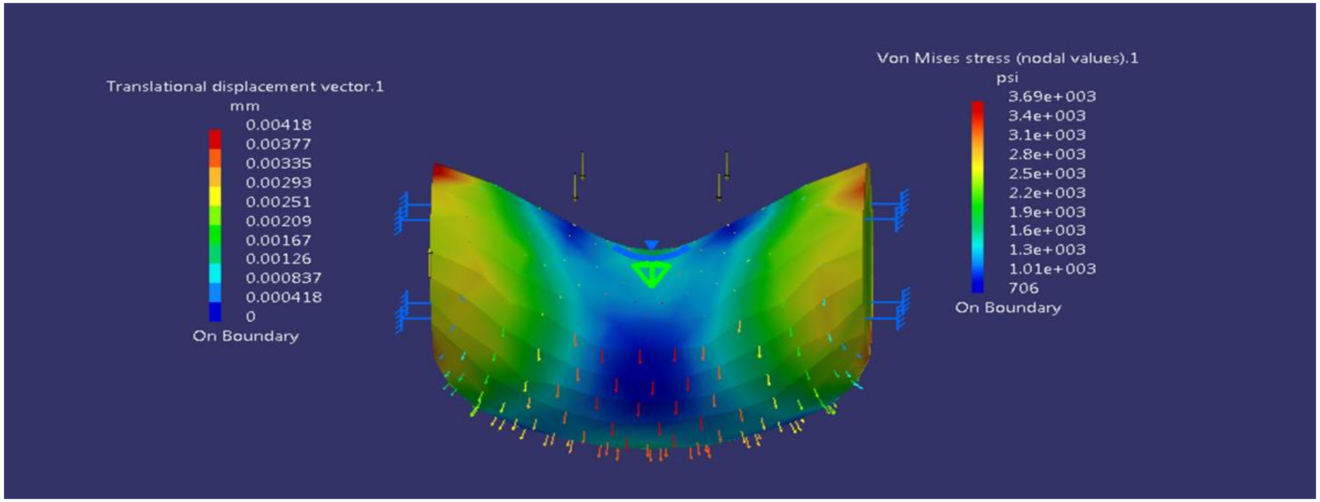
- Minimum Shaft Diam.
  - 28 mm
- Max. Dynamic Load
  - Shaft - 20.187 kN
  - Bearing - 20.59 kN
- Factor of Safety
  - 1.02

Intermediate Shaft

Bearing 1 Force	F1 =	8.235	kN					
Bearing 2 Force	F2 =	10.155	kN					
	Stage 1					Stage 2		
Desired Life	Ld =	10000	Hours		Desired Life	Ld =	10000	Hours
Speed of Input	nd =	420	rpm		Speed of Input	nd =	420	rpm
	Xd =	2.8			$x_D = \frac{L_D}{L_{10}} = \frac{60\mathcal{L}_D n_D}{L_{10}}$	Xd =	2.8	
Manufacturer	M =	1						
	x0 =	0						
	θ =	4.48			Ball bearing	a =	3	
	b =	1.5			Roller Bearing	a =	3.333333333	
Reliability	Rd =	98.00%			Needle Roller Bearing	a =	3.333333333	
Application Factor	af =	1.2						
	Bearing	Needle Roller Bearing						
	N	2.8				N	2.8	
	D	0.520				D	0.520484904	
Bearing 1 Stage 1					Bearing 1 Stage 2			
	C10	16.371	kN			C10	16.371	kN
Double Bearing Used		8.185	kN		Double Bearing Used		8.185	kN
Value from Table		17.9	kN		Value from Table		17.9	kN
Bore for Roller	b =	25	mm		Bore for Roller	b =	25	mm
Outer Diameter	OD =	30	mm		Outer Diameter	OD =	30	mm
Width	W =	17	mm		Width	W =	17	mm
Shoulder Diameter	ds =		mm		Shoulder Diameter	ds =		mm
	dh =		mm			dh =		mm
Fillet Radius	r =		mm		Fillet Radius	r =		mm
Bearing 2 Stage 1					Bearing 2 Stage 2			
	C10	20.187	kN			C10	20.187	kN
Double Bearing Used		10.094			Double Bearing Used		10.094	
Value from Table		20.5	kN		Value from Table		20.5	kN
Bore for Roller	b =	28	mm		Bore for Roller	b =	28	mm
Outer Diameter	OD =	35	mm		Outer Diameter	OD =	35	mm
Width	W =	16	mm		Width	W =	16	mm
Shoulder Diameter	ds =		mm		Shoulder Diameter	ds =		mm
	dh =		mm			dh =		mm
Fillet Radius	r =		mm		Fillet Radius	r =		mm
Diameter of Output Shaft	Do =	28	mm					
		1.10	in					

Deflection Analysis – Shafts





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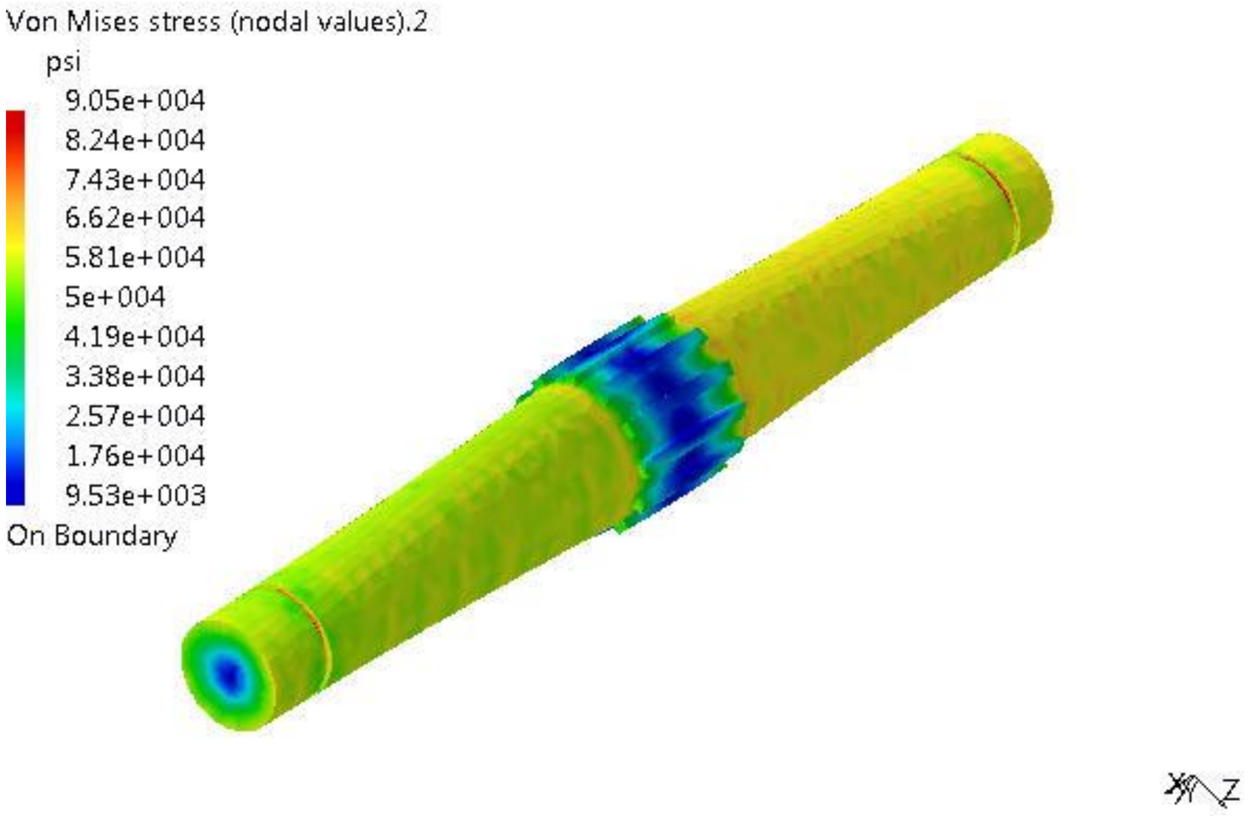

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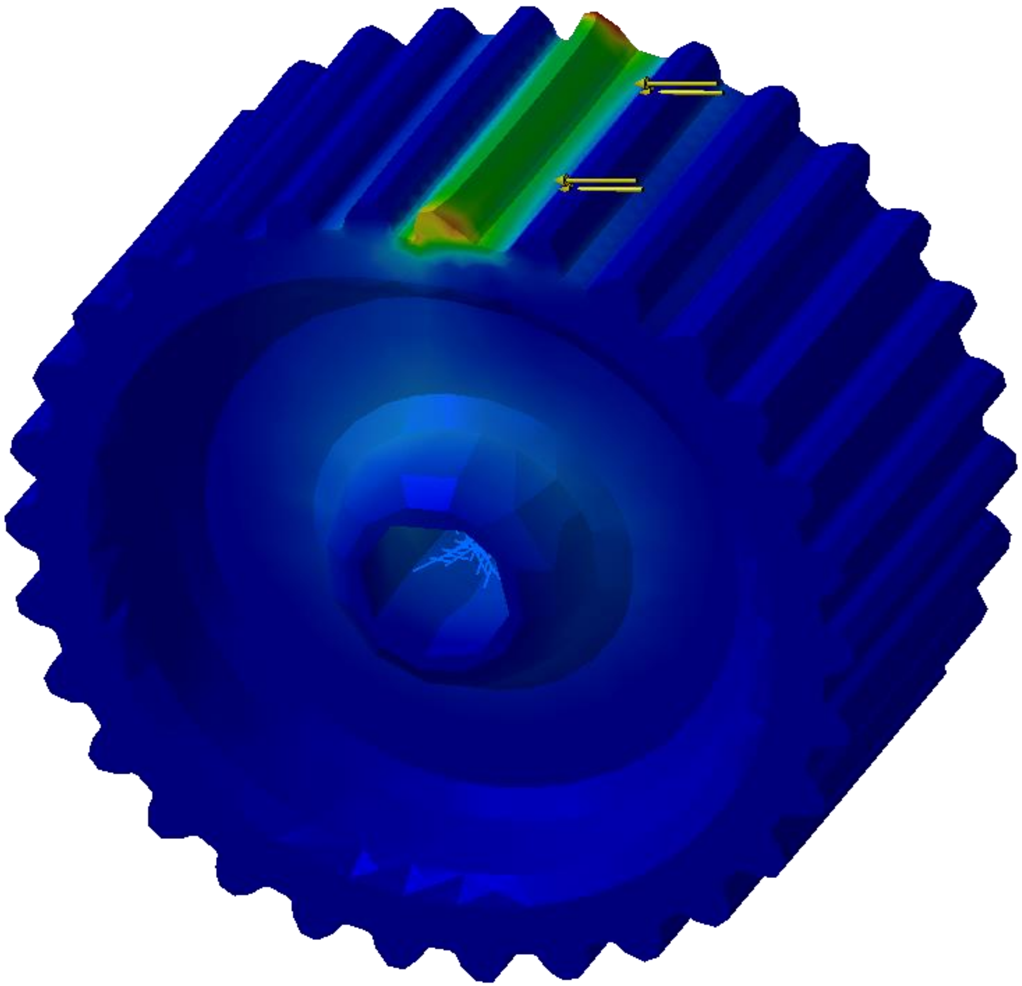
Deflection Analysis – Gear Teeth



Results

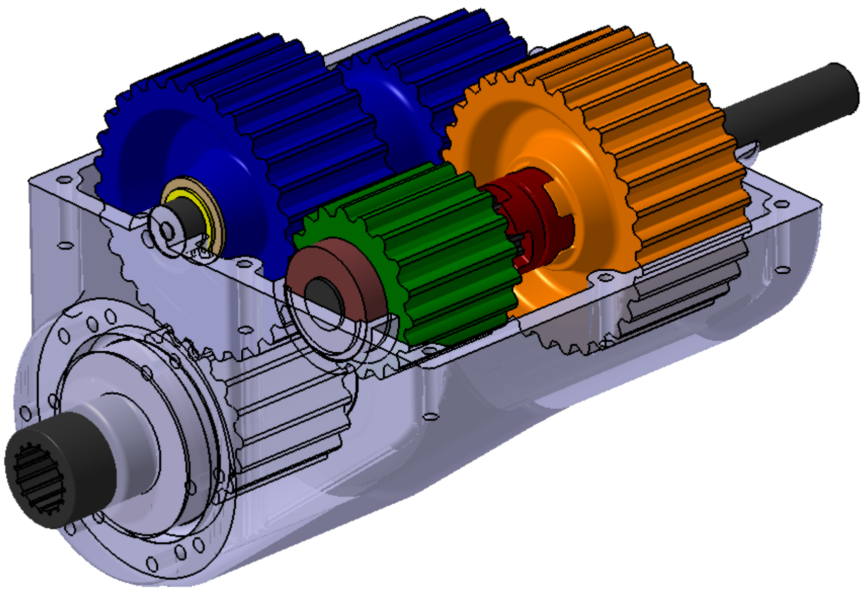
- Gear Failure Analysis indicates failure of gear #5
- Bending stress
  - 51.08 kpsi
- Bending Factor of Safety
  - Sf = 1.350
- Contact stress
  - 22.8 Mpsi
- Contact Factor of Safety
  - 0.0074
- Due to gearbox size constraints
- Gear is undersized

Parameters for a working Gearbox

- The major player in the factors that effected the contact stress was
  - Diameter
  - Number of Teeth
  - Geometry Factor
- Would need almost a 9” diameter

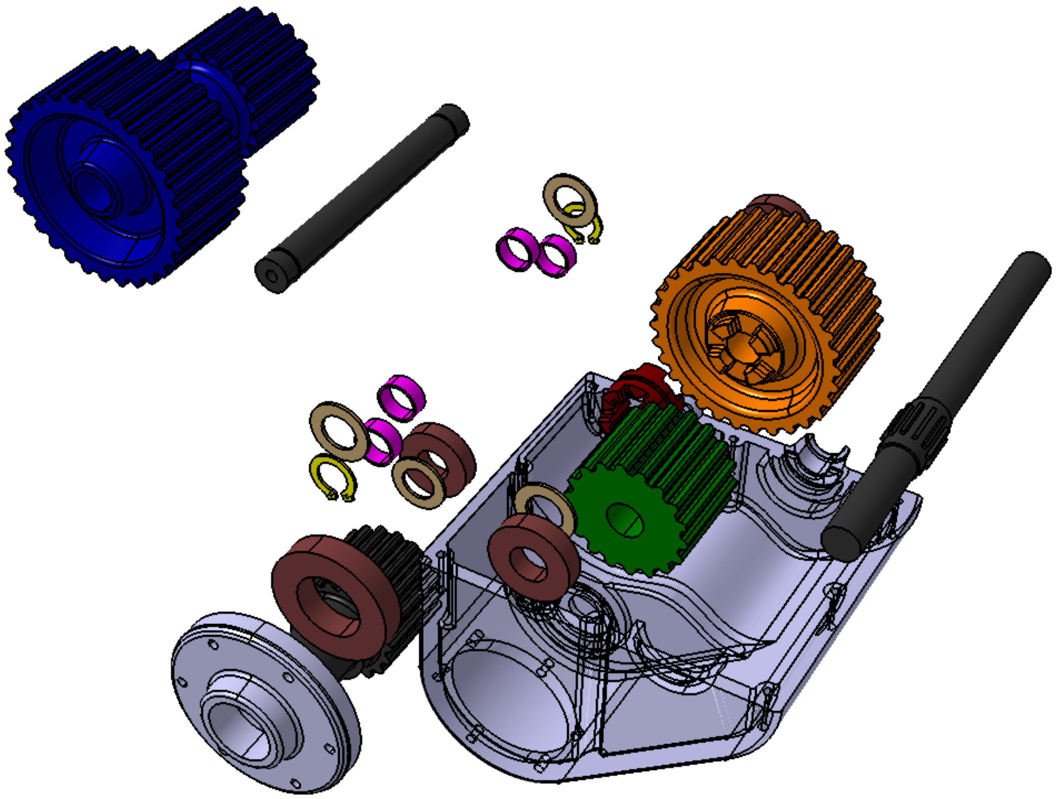
End Result

- The final assembly



End Result

- Exploded View



Working Gearbox