Modelling and Analysis of a Two-Stage Gearbox



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Abstract The world today as we know it is advancing in many factors as per manufacturing and design. One of the key factors during this process is to reduce weight and volume without changing the performance of the required product. This can be achieved by the selection of materials and manufacturing processes. In this study, a two-stage reduction gearbox was designed and analysed for its use on an all-terrain vehicle (ATV). Computer-aided design (CAD) and computer-aided engineering (CAE) software packages are used for designing and analysis of gears and shafts. A similar approach was adopted for designing of gears and shafts, whereas sequential approach thereafter for the design of casing geometry. The product was designed in accordance with the American Gear Manufacturers Association (AGMA) standards and is meant for off-road application.

Keywords Powertrain · Gears · All-terrain vehicle (ATV) · GearTraxPRO · SolidWorks · ANSYS

1 Introduction

For the all-terrain vehicles (ATV) that are configured for an automatic transmission drive using a continuously variable transmission (CVT), a gearbox has to be coupled with the CVT to get desired speed and torque output. Since the CVT is providing variable transmission ratios, a forward–neutral–reverse (FNR), two-step reduction gearbox can be used for this purpose. The work proposed here is to design a twostage gearbox consisting of both helical and spur gears. This gearbox is designed for an ATV, made for the BAJA competitions. Here weight reduction is focused upon as the main goal to achieve maximum acceleration and also to get the centre of gravity as low as possible. Thus, factors such as weight, strength and size are optimized

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Table 1	Input parameters	Input paramatars	Sign	Value
		input parameters	Sign	value
		Coefficient of friction	fr	0.16
		Mass of vehicle + driver	mf	225 kg
		Gradeability angle		30 degree
		Air Density	PI	1.199 kg/m ³
		Coefficient of drag	Cw	0.5
		Velocity of car	V = Vf	25 km/hr
		Acceleration of car	a	2.83 m/s ²
		Efficiency of CVT	E1	0.88

to achieve the best possible gearbox. The analysis operations conducted during the research were done according to Navneet et al. [1], in their study in 'Analysis and Simulation of Gearless Transmission Mechanism' and also by Timir Patel et al. [2], in their study 'Design and Analysis of an Epicyclic Gearbox for an Electric Drivetrain'.

2 Vehicle Parameters

Engine power = 10 hp = 7.456 kW @ Max RPM = 3800 rpm Engine torque = 19.2 Nm @ 2700 rpm Transmission type = CVT + Gearbox drive Gearbox type = forward spool two-stage helical gearbox Overall reduction = 9 Stage 1 reduction = 3, stage 2 reduction = 3 Gear material = 20 MnCr5, Yield strength: 350–550 N/mm², Tensile strength: 650–880 N/mm².

The Table 1 shows the parameters taken into account of an ATV for which the gearbox is being designed.

3 Torque Requirements

To determine the required torque, the most important factor that turns in is the total resistance experienced by the vehicle. The driving resistance is an important variable taken into consideration while designing transmission systems. Driving resistance is made up of mainly four resistances:

- Wheel Resistance
- Air Resistance
- Gear Resistance

Engine RPM	Total reduction	Engine (N-m)	Torque (N-m)	Traction (N)	Velocity (m/s)	Gradient	Acceleration (m/s ²)	Total resistance (N)
1800	27	18	487	1498	5.8	32	1.9	932
2000	26.4	18.7	494	1520	6.6	32.1	1.9	943
2200	25.9	18.8	487	1499	7.4	32.1	19	932
2400	24.7	18.9	467	1438	8.5	29.1	2	901
2600	23.4	19	445	1368	9.7	25.8	1.7	867
2800	22.5	19.1	430	1322	10.9	23.6	1.6	844
3000	19.8	18.9	374	1151	15.3	17.4	1.3	759
3200	15.3	18.8	288	887	23.6	12.7	0.9	626
3400	12.6	18.3	231	711	32.5	4.2	0.6	537
3600	11.7	18.2	213	655	40.8	1.5	0.6	510
3800	6.75	17.6	119	366	49.3	1	0.5	502

 Table 2
 Resistance calculations

• Acceleration Resistance.

The Table 2 comprises of the resistance values experienced by the ATV at different RPMs. As the engine increases its RPM, the resistance value changes [3–5].

Taking reference from the Table 2, we determined what is the exact reduction required for our BAJA vehicle [4, 6, 7].

4 Design of Gearbox

Design calculations of various parts of gearbox are as follows [4, 6–9].

4.1 Design of Gears

Lewis bending equation is.

$$\sigma = \frac{K_v W^t}{FmY} \tag{1}$$

where

 σ is the bending stress on gear teeth (not considering dynamic loading) *F* is the face width *m* is the module *W*^t is the tangential load *Y* is the Lewis form factor K_v is the velocity factor

AGMA bending stress equation is

$$\sigma = \frac{K_v W^t K_s K_o K_H K_B}{b m_t Y_J} \tag{2}$$

where

 σ is the bending stress-induced K_v is the dynamic factor W^t is the tangential transmitted load b is the face width of the narrower member K_o is the overload factor K_s is the size factor K_B is the rim thickness factor K_H is the load distribution factor Y_J is the geometry factor for bending strength m_t is the transverse module

AGMA pitting stress equation is

$$\sigma_c = Z_E \sqrt{W^t K_o K_v K_s \frac{K_H}{d_{wl} b} \frac{Z_R}{Z_I}}$$
(3)

where

 σ_C is the pitting stress-induced Z_E is the elastic coefficient d_{wl} is the pitch diameter of the pinion Z_I is the geometry factor of the pitting resistance Z_R is the surface condition factor

AGMA allowable bending stress equation is

$$\sigma_{\rm all} = \frac{S_t Y_N}{S_F Y_\theta Y_Z} \tag{4}$$

where

 S_t is the allowable bending stress Y_N is the stress cycle factor for bending stress Y_Z is the reliability factor Y_{θ} is the temperature factor S_F is the AGMA factor of safety.

Table 3 For reduction stage1 pinion and gear

Parameter	Value
Gear type	Spur
Helix angle	Zero
Pressure angle	20 degree
No. of teeth on pinion	18
No. of teeth on gear	54
Max. RPM	1267
Module	2
Face width	15 mm

AGMA allowable pitting stress equation is

$$\sigma_{c,\text{all}} = \frac{S_c Z_N Z_W}{S_H Y_\theta Y_Z} \tag{5}$$

where

 $\sigma_{c,all}$ is the allowable pitting stress

 Z_N is the stress cycle factor

 S_c is the allowable contact stress

 S_H is the AGMA factor of safety

 Z_W is the hardness ratio factors for pitting resistance.

To avoid failure in gearing, the following condition must be satisfied:

 σ (both of Lewis bending equation and AGMA strength equation) $\ll \sigma_{all}, \sigma_c \ll \sigma_{c, all}$.

Solving the above equations by inserting the specified vehicle parameters, the above conditions are satisfied. Therefore, the design is safe.

The values obtained by solving the equations in GearTraxPRO (Camnetics Suite) are shown in Table 3 for stage 1 pinion and gear and Table 4 for stage 2 pinion and gear.

The following tables show the parameters taken as for both pinion gears for design [3] (Table 5).

4.2 Design of Shafts

Parameters:

Material: AISI/SAE 4340 UTS: 925 MPa Yield strength: 680 MPa Allowable shear stress for shaft: 462.5 MPa

Parameter	Value
Gear type	Helical
Helix angle	20 degree
Pressure angle	20 degree
No. of teeth on pinion	18
No. of teeth on gear	54
Max. RPM	423
Module	2
Face width	25 mm

Table 5 Factors for spur andhelical gears

 Table 4
 For reduction stage

2 pinion and gear

Factors	Symbols	Value
Overload factor	Ко	1
Dynamic effect factor	Kv	1.178
Size factor	Ks	1.0029
Load distribution factor	Km	1.149
Rim thickness factor	Kb	1.139
Bending strength factor	Yj	0.317
Geometry factor	Ι	0.12
Temperature factor	Kt	1
Reliability factor	Kr	1
Hardness factor	Ch	1

Torque transmitted by pinion:

$$T = \frac{P \times 60}{2\pi N_P} \tag{6}$$

Equivalent no. of teeth:

$$T_E = \frac{T_P}{\cos^3 \alpha} \tag{7}$$

Tooth factor:

$$y' = 0.154 - \frac{0.912}{T_E} \tag{8}$$

Tangential tooth load:

$$W_T = \frac{2T}{m \times T_P} \tag{9}$$

$$\frac{1}{n} = \frac{16}{\pi d^3} \left\{ \frac{1}{S_e} \Big[4 (K_f M_a)^2 + 3 (K_{fs} T_a)^2 \Big]^{1/2} + \frac{1}{S_{ut}} \Big[4 (K_f M_m)^2 + 3 (K_{fs} T_m)^2 \Big]^{1/2} \right\}$$
(10)

where

Factor of safety (FOS) = nDiameter of the shaft = dEndurance limit at critical location $S_e = k_a k_b k_c k_d k_e k_f S'_e$ k_a is the surface condition modification factor k_h is the size modification factor k_c is the load modification factor k_d is the temperature modification factor k_e is the reliability factor k_f is the miscellaneous effects modification factor S'_{e} = rotary beam test specimen endurance limit Stress concentration factor for Bending, $K_f = 1 + q(K_t - 1)$. Stress concentration factor for torsion, $K_{fs} = 1 + qshear(K_t - 1)$. q is the notch sensitivity M_e is the midrange bending moment M_a is the maximum bending moment T_a is the alternating torque T_e is the maximum torque S_{ut} is the tensile strength.

By drawing shear force and bending moment diagrams, we are able to find the values of M_a and T_e .

Resultant bending moment: $Ma = \sqrt{(M_1)^2 + (M_2)^2}$.

Putting the values in Eq. 10, we get n = 1.37.

From the above equation, we get $d_P = 17$ mm (standardized according to the availability of support bearing sizes and oil seals).

The value of principal shear stress is equated which is significantly less than the permissible shear stress of the shaft material. Hence, the design is safe.

Repeating the above calculations for the intermediate shaft and the output shaft, we get shaft diameters as **22 mm** and **27 mm**.

4.3 Design of Casing

The casing design was aimed at achieving the lowest possible volume, while constraining the shafts with gears mounted on them. The geometry is kept simple for lowering the machining cost.

5 CAD Modelling of Gears, Shafts and Casing

SolidWorks 2018–19 modelling software was used to design the various components of the gearbox. Based on the input design parameters from GearTraxPRO software, modelling was done in SolidWorks. The images of the components are shown in the figures below. Gear material was selected as 20MnCr5 [10]. Figures 1 and 2 show the gears of the first stage reduction of the gearbox. Figures 3 and 4 show the gears of the second stage reduction of the gearbox. Figures 5, 6 and 7 show the CAD model of the input shaft, intermediate shaft and output shaft, respectively. Figures 1, 2, 3, 4, 5, 6 and 7 are the gears and shafts designed as per parameters in SolidWorks [11, 12, 17].

Fig. 1 Spur pinion



Fig. 2 Spur gear



Fig. 3 Helical pinion



Fig. 4 Helical gear



Fig. 5 Input shaft





Fig. 6 Intermediate shaft





The CVT is coupled with the input shaft with the help of the keyway in the input shaft. The casing design was optimized for minimum machining cost by reducing the number of contours that were made keeping in mind the weight of the gearbox. Following Figs. 8 and 9 show the final geometry including the left and right casing sides. Aluminium 6061-T6 was chosen as casing material [11].

The final assembly was done using SolidWorks, which included all the gears, shafts, bearings and the shifter. Figures 9 and 10 show the assembled view of the gearbox.



Fig. 8 Exploded view of complete gearbox

Fig. 9 Assembled view of gearbox without casing



Fig. 10 Complete assembly of gearbox



6 Static Analysis

6.1 Gears

Maximum loading conditions were assumed for checking the gears for maximum safety. It was assumed that the worst loading condition on the gearbox would be when the vehicle is stuck and the engine is working at full power to get out of the obstacle. At this point of time, maximum torque would fall on the intermediate shaft gear 3. In the result, maximum stress-induced under full-loading condition was less than maximum allowable stress for the selected material [1]. The following pictures are of the analysis done on gears on ANSYS software [5, 12–14, 16].

Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1.	0. •	5.897e-002

Gear teeth are subjected to both bending and wear. The section where it experiences the maximum stress is the root of the tooth. It is considered that there are three teeth in contact with the mating gear [12]. Tangential force (Ft) because of the torque which the gear is transmitting is applied on these three teeth. The total tangential force is distributed amongst the three teeth considering one tooth takes 50% of force and others take 25% each. The radial forces (Fr) generated on the gear are acting towards the centre of the gear [12, 13].

Magnitudes of the tangential and radial forces for the application in the analysis are taken from the GearTraxPRO output values in the design of the gears. The analysis result shows that the design is safe, even when the worst loading condition is considered. Figures 11, 12 and 13 show the dimensioning and force calculation outputs for reduction set 1 (for gear 1 and gear 2). The results were obtained by simulation in ANSYS software. Based on the results and analysis, we chose EN24 as our material for gear manufacturing [10] (Fig. 14).

6.2 Shafts

Shafts are mainly subjected to bending and torsion. It is considered that the shafts are subjected to maximum torsion at the location of gear through spline. Hence, the torque is applied at that position. Bearing portion where taken as the frictionless support and the fixed support will be the output of the shaft at both ends where the drive shaft through the joints will attach [5, 14, 15] (Figs. 15, 16 and 17).



Fig. 11 Force model of gear



Fig. 12 Equivalent stress of gear



Fig. 13 Total deformation model



Fig. 14 Factor of safety of gear



Fig. 15 Force model of output shaft

6.3 Casing

See Figs. 18, 19, 20 and 21.



Fig. 16 Equivalent stress of output shaft



Fig. 17 Factor of safety of output shaft

7 Software Results for Gear Design (GearTRAXPRO)

The following pictures are screenshots of the GearTRAXPRO software while obtaining a SolidWorks part file of the gear. It also includes all parameters taken into consideration for designing the gear.



Fig. 18 Force model of casing



Fig. 19 Contact region



Fig. 20 Equivalent stress of casing

Figures 22 and 23 show the dimensioning and Figs. 24, 25, 26, 27, 28 and 29 force calculation outputs and other parameter calculations for reduction set 1 (for gear 1 and gear 2). The results were obtained by simulation in GearTraxPRO software.





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Fig. 22 Gear set 1 dimensioning

8 Conclusion

Comparison of existing alternative options in the market and this new design of the gearbox show that there is a significant reduction in weight of the gearbox. This is achieved while keeping the performance parameters as required by the potential

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Fig. 23 Gear set 2 dimensioning

customers. The gearbox design was finalized in geometry and material (in accordance with AGMA standards) and was forwarded to manufacturers [3] for getting a prototype model for testing. Once manufactured, the model will be tested on a BAJA ATV, by replacing the old gearbox with this gearbox. An overall weight reduction of 9.5 kg is expected from the design, when compared with its alternative market option.

ools	Help					
ading	Bending Strength	Pitting Resistance				
P	itting Resistance of	Gear Set - for metallic spur	gears (1500) FPM max	for this formula)	
	u = Poisson's R	atio	0.3		GEAR 0.3	
	E = Modulus of	Elasticity PSI	3,04,9	57,920.0	3,04,57,920.0	
	Cp = Elastic Co	efficient		2308.02		
	Wt = Transmitte	ed Tangential Load, LB		526.9		
	Ko = Overload	Factor		1.00		
	Kv = Dynamic I	actor		1.18		
	Ks = Size Facto	n		1.00		
	Km = Load Dist	ribution Factor		1.00		
	Cf = Surface Co	ondition Factor		1.00		
	ZN = Stress Cy	cle Factor		0.92		
	CH = Hardness	Ratio Factor		1.00		
	SH = Safety Fa	ctor		1.00		
	KT = Temperat	ure Factor		1.00		
	KR = Reliability	Factor		0.99		
	K = Contact Lo	ad Factor PSI		739.69		
	CG = Gear Rati	o Factor		0.75		
	Lmin, Face Wid	ith of Narrowest Member		0.63in		
	I = Geometry Fa	actor for Pitting Resistance		0.18900		
	Kac = Allowa	ble Contact Load Fact	or PSI	1316.46		
	cs = Contact	Stress PSI Actual		1,35,833	8.5	
	sac = Allowable	Contact Stress, PSI		1,95,000	.0	

Fig. 24 Pitting resistance for gear set 1

≥ Ext	ternal Spur Sizing - Beta 1 - AGMA 908-B89 &	2001-D04	×
Tools	Help		
Loading	Bending Strength Pitting Resistance		
E.	Beam Strength of Gear Set		
		PINION	GEAR
	T = Torque IN LBS	397.3	1191.9
	Input HP	7.6742	
	REQ W = Tooth Load, LBS (along pitch line)	52	26.9
	RPM	1217.3900	405.7967
	S = Safe Material Stress (Static) PSI	34,954.0	34,954.0
		Bronze 10,000	~
	V = Pitch Line Velocity Feet/Minute	480	.9668
	Number of Teeth	18	54
	DP = Diametral Pitch, Normal	12.7	70289
	PSI(s) = Helix Angle	20.00	000deg
	G = Face Width	0.6299in	0.6299in
	Tooth Thickness Area	0.0998in^2	0.1147in^2
	W = Tooth Load Safe, LBS	709.1	879.3
	Tooth Thickness PSI Capacity	7104.2	7663.4
	Tooth Thickness PSI Actual	5279.2	4592.6
	Show Parat	bola	O (Î) → []
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Fig. 25 Force calculations for gear set 1

Tools	Help			
oading	Bending Strength Pitting Resistance			
В	ending Strength Geometry			
	Type of Loading	Loading_at_HF	PSTC ~	
		PINION	GEAR	
	anL = Load Pressure Angle	20.05deg	21.45deg	
	hF = Height of Lewis Parabola	0.0812in	0.0889in	
	sF = Tooth Thickness at Critical Section	0.1585in	0.1822in	
	Ch = Helical Factor	1.0000	1.0000	
	Kpsi - Helix Angle Factor	1.0000	1.0000	
	oF = Minimum Radius of Curvature	0.0316in	0.0275in	
	mN = Load Sharing Factor	1.000000	1.000000	
	CV = Helical Overlap Factor	1.366170	1.366170	
	mF = Axial Contact Ratio	0.871116	0.871116	
	Kf = Stress Correction Factor	1.9065	2.0221	
	Y = Tooth Form Factor (calculated)	0.6926	0.8588	
	J = Geometry Factor for Bending Strength	0.4963	0.5802	
	Bending Strength Options Use minimum tooth thickm Use alternative sizing meth Use cutter tip as minimum	ess nod radius		
	Chau Bashala			1

Fig. 26 Bending strength for gear set 1

Working Pressure Angle		
Working Pressure Angle: 21.173de	eg	
Roll Angles		
	PINION	GEAR
Roll Angle at Custom Diameter:	22.19deg @ 38.310m	22.19deg @ 114.931r
Roll Angle at Operating Diameter:	22.1	9deg
Roll Angle at HPSTC	26.07deg	24.14deg
Roll Angle at LPSTC:	16.36deg	20.90deg
Roll Angle at Major Diameter:	36.36deg	27.57deg
Roll Angle at Profile Modification APL:	A profile modification /	A profile modification /
Roll Angle at Profile Modification BPL:	A profile modification {	A profile modification {
Roll Angle at TIF Diameter:	3.39deg	15.93deg

Fig. 27 Pressure angle for first stage reduction

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Fig. 28 Operating parameters for reduction gear 1

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Fig. 29 Contact ratios for gear set 1

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References

- Bardiya N, Karthik T, Rao LB (Sep 2014) Analysis and simulation of gearless transmission mechanism. Int J Core Eng Manag (IJCEM) 1(6)
- 2. Patel T, Dubey A, Rao LB (Sep 2019) Design and analysis of an epicyclic gearbox for an electric drivetrain. Int J Recent Technol Eng (IJRTE) 8(3). ISSN: 2277-3878
- 3. Herring DH, Otto FJ, Specht FR (2013) Gear materials and their heat treatment. BNP Media
- 4. Payne ET (2015) Design of an SAE baja racing off-road vehicle powertrain. The University of Akron in Akron, Ohio, USA, Spring

- 5. Sekhar K, Dharmadhikari P, Panchal S, Rao LB (2020) Design and optimization of a two stage gearbox using GEARTRAX. Recent Trends Mech Eng, Lect Notes Mech Eng 445–477
- 6. Ashby M (2001) Materials and process selection for engineering design, 3rd ed. Pergamon Press, Ch. 4, pp 110–144
- 7. Sharma A, Singh J, Kuma A (June 2015) Optimum design and material selection of baja vehicle. Int J Curr Eng Technol 5(3)
- 8. PSG (2006) PSG design data book, PSG college of technology. Kalaikathir Achchagam
- 9. Budynas R, Nisbett K (2006) Shigley's mechanical engineering design, 8th edn, Ch 3, sec 14. pp 711–762
- 10. Gligorijević R (1976) Materials for gears manufacturing their dynamic and structural characteristics and heat-treatment. J Technol 5(6):367–379
- Gupta A, Yashvanth VP, Rao LB (2020) Design of gears using aluminium 6061-T6 alloy for formula SAE steering system. Recent trends in mechanical engineering, lecture notes in mechanical engineering. pp 489–505
- 12. Vara Prasad V, Satish G, Ashok Kumar K (2013) Trade of analysis for helical gear reduction unit. Int J Eng Res Technol 2(11):54–63
- Aru S, Jadhav P, Gajabhiye S, Jadhav V, Angane P (2014) Design and analysis of centrally suspended cage-less differential. Int J Mech Prod Eng Res Develop 4(4):49–60
- Anand S, Srikeshav AD, Sharran B, Rao LB (2020) Design and analysis of helical teeth harmonic drive. Recent trends in mechanical engineering, lecture notes in mechanical engineering. pp 507–519
- Gujaba KP, Parashar S, Rao LB (2020) Design and analysis of permanent magnetic gears. Recent trends in mechanical engineering, lecture notes in mechanical engineering. pp 521–530
- 16. ANSYS user manual, Version 14
- 17. Solidworks user manual (2020)