Design of Rear Wheel Transmission

ME3201 - Design of Machine Elements

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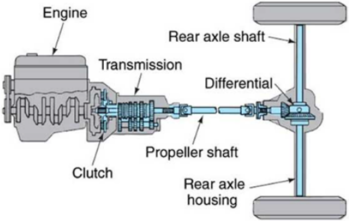
Introduction

- Rear wheel transmission system transfers power from engine to rear wheels efficiently

- **System components:**
  - **Propeller shaft:** Transmits power from the transmission to the rear differential.
  - **Differential unit:** Splits power to the rear wheels, letting them spin at different speeds.
  - **Axle shafts:** Carry power from the differential out to the rear wheels.
  - **Keys:** Lock internal differential gears onto their respective shafts.
  - **Bearings:** Support the rotating propeller shaft and rear axle components to reduce friction.



Main Components

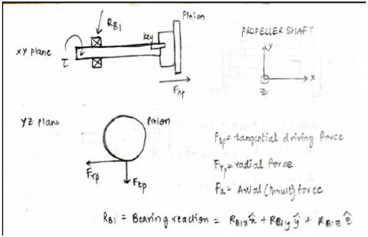
Input Parameters:

- Power: $P = 182$ BHP $= 135.717$ kW
- Engine speed: $N = 3500$ rpm
- Engine torque: $T_{\text{eng}} = 370.28$ Nm

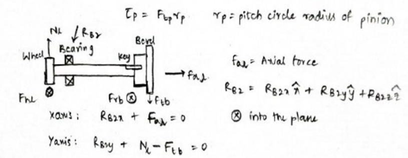
Assumed Vehicle Specifications:

- **Vehicle weight =** 2500 kg
- **Gearbox first gear ratio =** 4.1
- **Propeller Shaft:** It is considered to be hollow with a length of 1.5m
- **Axle Shaft:** It is considered to be solid with a length of 0.8m.

Free Body Diagrams



Propeller Shaft



Axle Shaft

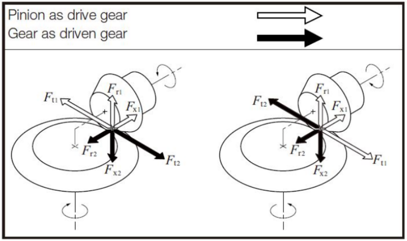
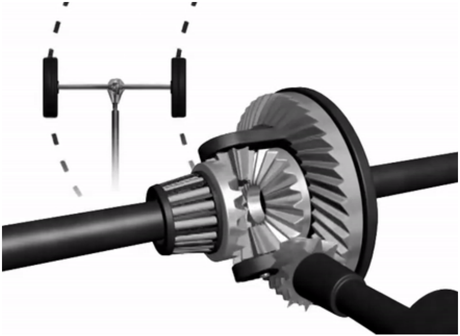


Figure: Differential Unit

Differential Theory

Purpose:

- Allows wheels to rotate at different speeds during turning
- Distributes equal torque to both wheels
- Accommodates 90-degree power transmission



Turning Analysis

Given Parameters:

- Vehicle speed: $v = 30$ km/h
- Turning radius: $R = 7.079$ m
- Shaft length + allowance: $r = 0.925$ m
- Wheel radius: $r_w = 0.216$ m

Angular Velocity:

$$\omega = \frac{v}{R} = 15.024 \text{ rpm}$$

Wheel Speeds:

$$\omega_{\text{inner}} = \frac{(R - r)\omega}{r_w} = 214.122 \text{ rpm}$$

$$\omega_{\text{outer}} = \frac{(R + r)\omega}{r_w} = 278.49 \text{ rpm}$$

Speed Difference: $\Delta\omega = 64.37$ rpm (30% faster outer wheel)

Hollow shaft: $d_i = 0.7 d_o$ Material: AISI 1040 HR Steel

$\text{T}_{\text{prop}} = (T_{\text{eng}} \times i_g)$

Loading: Fluctuating (0 to max) - $T_a = T_m = \frac{T_{\max} - T_{\min}}{2}$

Endurance Limit Calculation:

Marin Factors are calculated from the tables for assumed conditions

$$S_e = k_a k_b k_c k_d k_e$$
$$S_{se} = 0.577 S_e$$

Shear stress Calculations:

$$\tau_a = \tau_m = K_{fs} \frac{T_a (d_o/2)}{J}$$

Goodman Criterion for Fluctuating Torsion:

$$\frac{\tau_a}{S_{se}} + \frac{\tau_m}{S_{su}} = \frac{1}{n_f}$$

Result:(For $n_f = 2$) $d_o = 86.67$ mm, $d_i = 60.67$ mm

$L_{axle} = 0.8m$
Wheel load = 625kg (per wheel)
Material: AISI 1040 HR Steel
$T_{axle} = \frac{1}{2} \times (T_{prop} \times i_f)$
Bending Moment: (Completely Reversed)

$$M_{max} = L\sqrt{F_{lat}^2 + F_{vert}^2}$$

Stress Calculations:

$$\sigma_a = K_f \frac{M_a c}{I}$$

$$\tau_a = \tau_m = K_{fs} \frac{T_m c}{J}$$

ASME Elliptical Criterion for Combined Loading:

$$\left(\frac{n_f \sigma'_a}{S_e}\right)^2 + \left(\frac{n_f \sigma'_m}{S_y}\right)^2 = 1$$

where von Mises equivalent stresses:

$$\sigma'_a = \sqrt{\sigma_a^2 + 3\tau_a^2}, \quad \sigma'_m = \sqrt{3\tau_m^2}$$

Result: (For $n_f = 2$) $d = 87.73$ mm

Propeller Shaft Key:

- Dimensions: $b \times h \times l = 20.91 \times 20.91 \times 125.45$ mm
- Shear stress: $\tau = 13.85$ MPa (allowable: 40 MPa)
- Crushing stress: $\sigma_c = 27.6$ MPa (allowable: 80 MPa)

Bearings (Deep Groove Ball, $L_{10} = 100 \times 10^6$ rev):

- **Axle bearings:** SKF 6317 (85 mm bore, $C = 41.96$ kN, FOS $= 2.29$)
- **Ring gear bearing:** SKF 6413 (85 mm bore, $C = 86.03$ kN, FOS $= 1.12$)
- **Propeller bearing:** SKF 6215 (85 mm bore, $C = 111.55$ kN, FOS $= 1.04$)

Design and Model - Bevel Gears

Bevel Gear Specifications

Property	Bevel Pinion	Ring Gear	Spider Gear	Side Gear	Units
Power (H)	179.5		25		HP
Angular Velocity (n)	3500	1440	280	280	rpm
Number of Teeth	20	48	18	18	-
Pressure Angle	20°				deg

- Operating temperature: 95°C
- Reliability: 0.99

$$S_c = C_p \left(\frac{W^t}{F\, d_P\, I} K_o\, K_v\, K_m\, C_s\, C_{xc} \right)^{1/2}$$

$$S_t = \frac{W^t}{F} P_d\, K_o\, K_v \frac{K_m\, K_s}{K_x\, J}$$

Design and Model - Bevel Gears

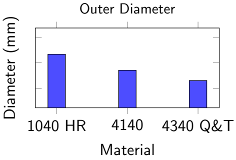
Bevel Gear Factors Obtained

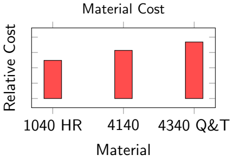
Factor	Bevel Pinion	Ring Gear	Spider Gear	Side Gear
K_o	1.75 (medium shock)			
K_v	1.5908		1.1.68	
K_s	0.525		0.525	
K_m	1.264		1.264	
K_x	1 (straight bevel gears			
K_L	0.999	0.971	0.999	
K_T	1			
K_R	0.999..			
C_s	0.683		0.683	
C_P	2290 (steel)			
C_{xc}	1.5 (crowned)			
C_L	1.319	1.250	1.319	
I	0.081		0.059	
J	0.245	0.199	0.191	

Cost Analysis

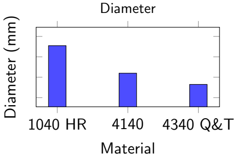
Material Comparison at FOS = 2.0

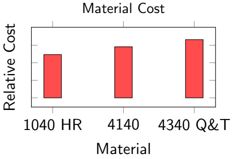
Propeller Shaft





Axle Shaft





Selected Material: AISI 1040 HR for lowest cost

Material Cost vs Performance:

- AISI 4340 Q&T reduces propeller shaft weight by 12.4% but increases cost by 48.2%
- AISI 4340 Q&T reduces axle shaft weight by 20.5% but increases cost by 34.5%
- Higher-strength materials enable 6–12% smaller diameters

Final Selection: AISI 1040 HR

- **Most economical option** for the complete system
- Relatively cheaper than AISI 4140 by approximately 17%
- Relatively cheaper than AISI 4340 Q&T by approximately 28%
- Optimal for mass-production automotive applications

Conclusion

Final Design Parameters:

- **Propeller shaft:** $d_o = 86.67$ mm (hollow, $d_i = 60.67$ mm)
- **Axle shaft:** $d = 87.73$ mm (solid)
- **Bearings:** Deep groove ball bearing $d_o = 130$mm, w=35mm
- **Keys on axle shaft:** 21.67 mm x 21.67 mm x 130.01 mm
- **Keys on propeller shaft:** 20.91 mm x 20.91 mm x 124.45 mm
- **Bevel Pinion:** $d_P = 128.47$ mm , F = 50 mm , $\gamma = 22.36°$
- **Ring Gear:** $d_P = 312.19$ mm , F = 50 mm , $\gamma = 67.64°$
- **Spider and Side Gears:** $d_P = 164.73$ mm , F = 33.98 mm , $\gamma = 45°$