Design of Rear Axle Gears for Commercial Vehicles

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Abstract

Most of the truck manufacturers have been confronted with ever more increasing demands on their products and on the development process. These demands are reflected in higher engine power, lower vehicle noise, higher fuel economy and shorter lead times in development .In most of commercial vehicle, single stage hypoid gears are used in the rear axles. Not only does this give a better fuel consumption: the noise level mostly is lower. Also the number of rear axle part is smaller and hence the weight of a single ratio hypoid axle will be lower than of a two stage hub reduction axle. For this reason, this paper will be mainly focused on single stage hypoid rear axle gears Design.

Keywords: *Hypoid Gear, Commercial Vehicle, Rear Axle, Power, Noise*

1. Introduction

Since the beginning of automobile history, rear axles have been used in rear wheel driven vehicles, both in passenger cars as well as in commercial vehicles. In general, tractor-trailer combinations or truck-trailers are used for this type of transport of goods.

The total vehicle or combination weights now a day are maximum 40 or 44 tonne. For inter-regional or national transport, vehicles in the range of 25 to 35 tonne are used. In the medium range, such as inter-urban transportation, vehicle weights mostly range from 7 to 20 tonne. These types of vehicles may also include vehicles for transport of goods such as sand, stones, rock, wood, concrete as well as off-the-road vehicles for military application. Small commercial vehicles, the so called vans, are in use for vehicle weights from being 6 tonne. Here, both front and rear wheel drives are utilized. At the lower side of vehicle weights such as passenger cars and motorbikes, rear axle drive are applied, although on a more limited scale due to the increasing application of front wheel drive.

Almost all commercial vehicle over 6 tonne are equipped with rear wheel drive, where the power is transmitted from the engine though a gearbox and drive shaft system to the rear axle of the vehicle.

Generally, two types of rear axles are applied in rear wheel driven vehicles: the single reduction and the hub reduction rear axle. The single reduction rear axle consists of a spiral bevel or a hypoid gear. It is mostly used for typical long distance transport applications and it is most widely spread. The hub reduction axle is a two stage reduction axle, mostly consisting of a first stage spiral bevel gear reduction coupled with a planetary stage in each wheel hub.

The axle configuration leads to a relatively small crown wheel diameter. Therefore these axle types are mostly used for off-the –road vehicles, where ground clearance is a very important item. The rear axle ratio does mostly cover a range of 2.5 to 7, depending on the axle and vehicle type. Long distance transport axles normally have ratio of 3 to 4, whereas city busses will have a ratio of 4 to 6. These are however indicative values.

2. Hypoid Gear Nomenclature [1]

Pitch angle of pinion (gear) γ(ѓ) is the angle between an element of the pitch cone and its axis.

Pitch apex beyond crossing point on the pinion (gear) G (Z) is the distance between the pitch apex and the crossing point on a hypoid set.

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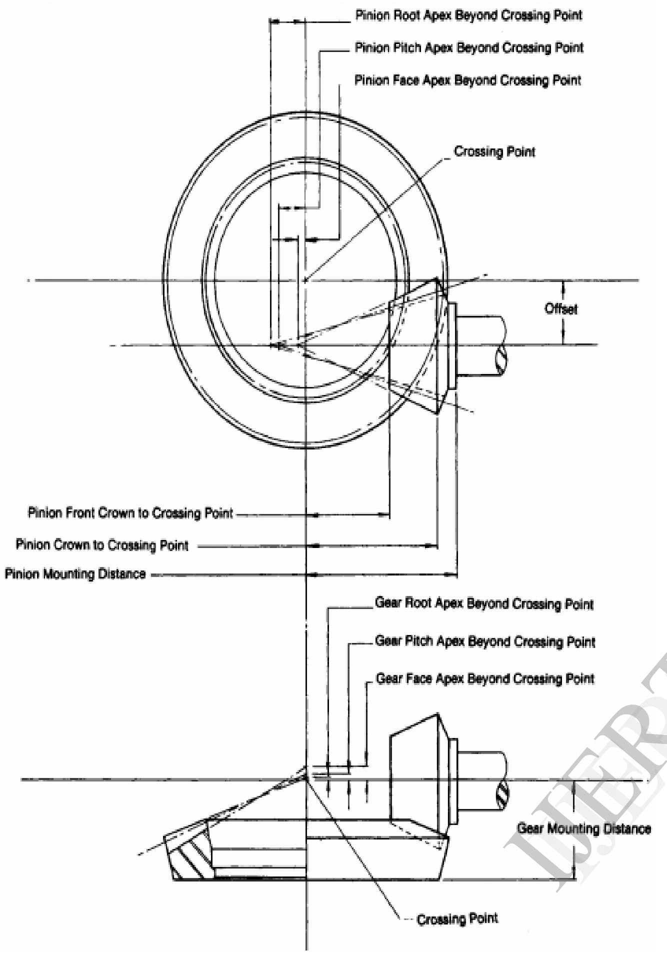

Fig.1 Hypoid Gear Nomenclatures

Pitch diameter of pinion (gear) d (D) is the diameter of the pitch cone at the out-side of the blank.

Pitch, mean circular p_m is the distance along the pitch circle at the mean cone distance between corresponding profiles of adjacent teeth.

Pressure angle ø is the angle at the pitch point between the line of pressure which is normal to the tooth surface and the planet angent to the pitch surface. It is specified at the mean cone distance.

Ratio, gear m_G is the ratio of the number of gear teeth to the number of pinion teeth.

Root angle of pinion (gear) γ_R ($\acute{r}_R$) is the angle between an element of the root cone and its axis.

Root apex beyond crossing point on the pinion (gear) G_R (Z_R) is the distance between the root apex and the crossing point on a bevel or hypoid set.

Shaft angle ∑ is the angle between the axes of the pinion shaft and the gear shaft.

Spiral angle ψ is the angle between the tooth trace and an element of the pitch cone. It is specified at the mean cone distance.

Spiral-bevel gear, left hand is one in which the outer half of a tooth is inclined in the counter clockwise direction from the axial plane through the midpoint of the tooth ,as viewed by an observer looking at the face of the gear.

Spiral-bevel gear, right-hand is one in which the outer half of a tooth is inclined in the clockwise direction from the axial plane through the midpoint of the tooth, as viewed by an observer looking at the face of the gear.

Tangential force W_t is the force applied to a gear tooth at the mean cone distance in a direction tangent to the pitch cone and normal to a pitch-cone element.

Thickness of pinion (gear), mean circular t (T) is the length of arc on the pitch cone between the two sides of the tooth at the mean cone distance.

Thickness of pinion (gear), mean normal Chordal t_{nc} (T_{nc}) is the Chordal thickness of the pinion tooth at the mean cone distance in a plane normal to the tooth trace.

3. Calculation Method [1]

3.1 Selection of Type of Gear

Hypoid gears are recommended where peripheral speeds are in excess of 1000 ft/min and the ultimate in smoothness and quietness is required. They are somewhat stronger than spiral bevels. Hypoid have lengthwise sliding action, which enhances the lapping operation but makes them slightly less efficient than spiral-bevel gears.

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3.2 Estimated Gear Size

Given gear torque and the desired gear ratio, the charts give gear pitch diameter. The charts are based on case-hardened steel and should be used as follows: As per standard specification, we take Torque = 2000 Nm = 17701 lb-in (1Nm= 8.8507 lb in) [2]

Calculating overall gear ratio If the transmission gear ratio is 1.5: 1 And the final drive gear ratio is 3:1,The total final drive ratio is 4.5:1,That means 1.5 X 3 = 4.5 = n/N[3]

1. For other materials, multiply the gear pitch diameter by the material factor from Table 1.

Table: 1 Material Factors C_M

Gear		Pinion		Material factor C_M
Material	Hardness	Material	Hardness	
Case-hardened steel	58 R_C†	Case-hardened steel	60 R_C†	0.85‡
Case-hardened steel	55 R_C†	Case-hardened steel	55 R_C†	1.00
Flame-hardened steel	50 R_C†	Case-hardened steel	55 R_C†	1.05
Flame-hardened steel	50 R_C†	Flame-hardened steel	50 R_C†	1.05
Oil-hardened steel	375–425 H_B	Oil-hardened steel	375–425 H_B	1.20
Heat-treated steel	250–300 H_B	Case-hardened steel	55 R_C†	1.45
Heat-treated steel	210–245 H_B	Heat-treated steel	245–280 H_B	1.65
Cast iron		Case-hardened steel	55 R_C†	1.95
Cast iron		Flame-hardened steel	50 R_C†	2.00
Cast iron		Annealed steel	160–200 H_B	2.10
Cast iron		Cast iron		3.10

†Minimum values.
‡Gears must be file-hard.

From Fig 2 Gear pitch diameter based on surface durability Gear pitch diameter in inch = 10.5 inch = 11 inch = 279.4 mm = 280 mm

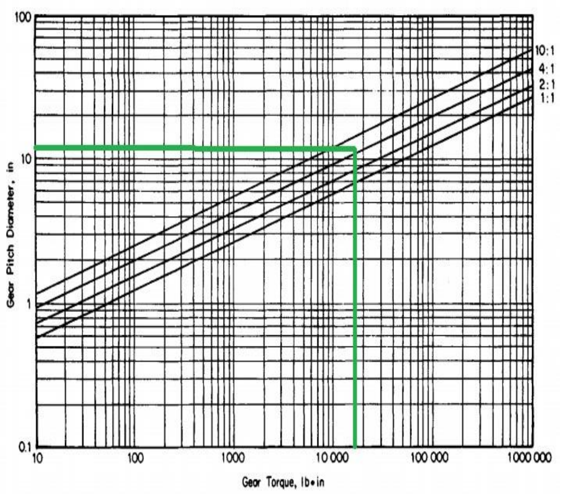

Fig. 2 Gear pitch diameter based on surface durability

From Fig 2 Gear pitch diameter based on surface durability Gear pitch diameter in inch = 10.5 inch =280 mm.

For high-capacity ground spiral-bevel and hypoid gears, the gear diameter from the durability chart should be multiplied by 0.80.

Gear diameter = 0.8 X 280 = 224 mm for hypoid gears, multiply the gear pitch diameter by D/ (D+E).

Gear pitch diameter = X D / (D + E) =249 mm, Where E = Offset = 28 as per specification [4].

For statically loaded gears subject to vibration, multiply the gear diameter from the strength chart by 0.70.Gear diameter = 224 X 0.70 = 157 mm

For statically loaded gears not subject to vibration, multiply the gear diameter from the strength chart by0.60.Gear diameter = 135 mm

Estimated pinion diameter is d = D n/N.

= 35 mm = 1.37 inch

3.3 Number of Teeth

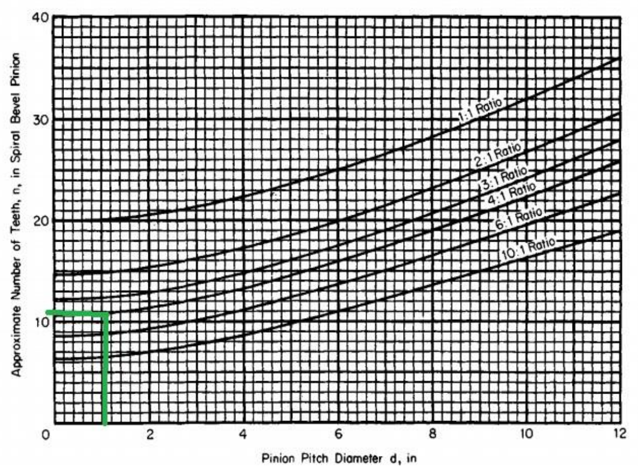

Fig. 3 Recommended tooth numbers for spiral-bevel and hypoid gears

From Fig. 3of recommended tooth number for hypoid pinion n = 10.8 is equal to 11.

Number of teeth for hypoid gear N = Gear ratio X n=50

3.4 Diametral Pitch

The Diametral pitch is now calculated by dividing the number of teeth in the gear by the gear pitch diameter.

Diametral Pitch = Number of teeth in the gear / Gear pitch diameter, p_d = 0.178 mm = 0.007 inch

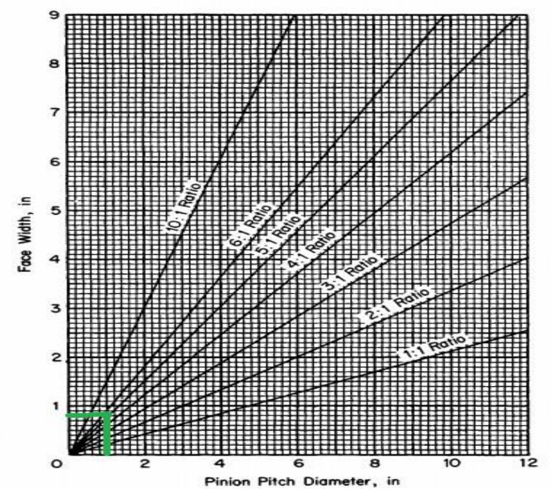

Fig. 4 Face width of spiral-bevel and hypoid gears

From Fig. 4 Face width of spiral-bevel and hypoid gears as per d = 1.37 inch, Face width F = 0.8 in = 20.32 mm=21mm

3.5 Spiral Angle

For hypoid gears, the desired pinion spiral angle can be calculated by

$$\psi_P = 25 + 5\sqrt{\frac{N}{n}} + 90\,\frac{E}{D}$$

Ψ_P = 43°

3.6 Pressure Angle

In the case of hypoid, the pressure angle is unbalanced on opposite sides of the Gear teeth in order to produce equal contact ratios on the two sides. For this reason, the average pressure angle is specified for hypoid. For automotive drives, use18° or 20°, and for heavy-duty drives, use 22.5°or 25°.

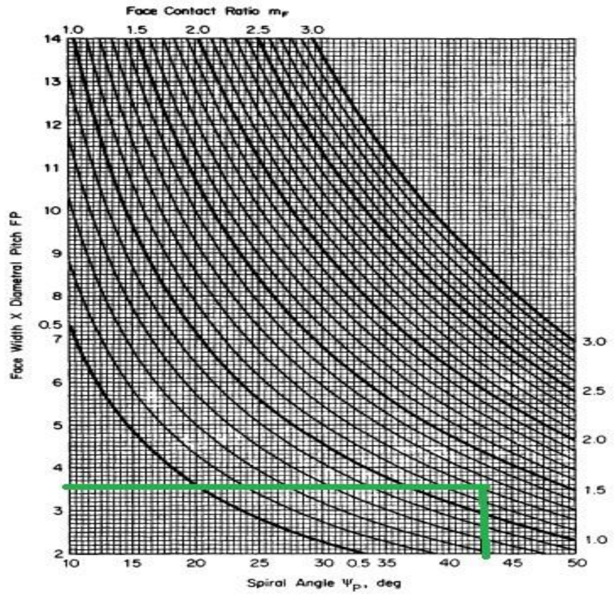

Fig. 5 Selection of spiral angle

From Fig. 5 selection of spiral angle

Face width X Diametral pitch = 21 X 0.178 = 3.738

Face contact ratio m_F = 1.2

3.7 Cutter Diameter

The usual practice is to use a cutter diameter approximately equal to the gear diameter. Cutter diameters are standardized. Therefore, Table3.3 is included to aid in cutter selection. Cutter radius rc = 3.750 mm

Table: 2 Standard Cutter Radii Corresponding to Various Gear Pitch Diameters for Hypoid Gears

Pitch diameter D of gear, in	Cutter radius r_c, in (mm)
3.000–5.250	1.750
3.875–6.750	2.250
4.250–7.500	2.500
5.125–9.000	3.000
6.500–11.250	3.750
7.750–13.500	4.500
9.000–15.750	5.250
10.250–18.000	6.000
12.000–21.000	7.000
13.750–24.000	8.000
15.500–27.000	9.000
18.000–31.500	10.500
21.750–60.000	(320)
27.250–75.000	(400)
34.250–100.000	(500)

3.8 Gears-Tooth Dimensions

3.8.1 Calculation of Basic Hypoid Gear Tooth Dimensions

1. Number of pinion teeth n = 11

2. Number of gear teeth N = 50

3. Diametral pitch P_d = 0.178 mm = 0.007 inch

4. Shaft angle ∑ = 90°

5. Face width F = 21 mm

6. Pressure angle ø = 20°

7. Spiral angle ψ = 43°

8. Hand of spiral (pinion), left-hand /right-hand (LH/RH) = As per application

9. Cutter radius r_c = 3.750 mm

Table: 3 Formulas for Computing Blank and Tooth Dimensions

Item	Item no.	Member	Formula	Answers
Pitch diameter	1	Pinion Gear	$d = \frac{n}{Pd}D = \frac{N}{Pd}$	d =35mm D=157mm
Pitch angle	2	Pinion Gear	$\gamma = tan-1\frac{sin\sum}{\frac{N}{n}+cos\sum}$ $\Gamma = \sum - \gamma$	γ=12.51° ŕ =77.49°
Outer Cone distance	3	Both	$Ao = \frac{0.50D}{sin\Gamma}$	A_0=378mm
Mean Cone Distance	4	Both	$Am = A0 - 0.5F$	A_m=368mm
Depth Factor k_1	5	Both	Table 4	K_1=4.000
Mean working depth	6	Both	$h = \frac{k1Am}{PdAO}cos\psi$	h=16mm
Clearance actor k_2	7	Both	Table 5	K_2=0.024
Clearance	8	Both	$c = k2\ h$	c =0.384mm
Mean Whole depth	9	Both	$hm = h + c$	hm = 16mm
Equivalent 90° ratio	10	Both	$m90 = \sqrt{\frac{N\ cos\gamma}{n\ cos\Gamma}}$	m_{90} = 4.5
Mean addendum factorC_1	11	Both	Table 6	C_1 = 0.170
Mean Circular Pitch	12	Both	$Pm = \frac{\Pi Am}{PdAO}$	P_m = 17mm
Mean Addendum	13	Pinion Gear	$ap = h - aG$ $aG = C1\ h$	a_P = 13mm a_G = 2.72mm
Mean Dedendum	14	Pinion Gear	$bp = hm - aP$ $bG = hm - aG$	b_P = 3mm b_G =13.2mm
Sum of Dedendum Angles	15	Both (Standard)	$\sum\delta = tan-1\frac{bp}{Am} + tan-1\frac{bG}{Am}$	∑δ = 2.47
Dedendum angle	16	Pinion Gear	$\delta P = tan - 1\frac{bp}{Am}$ $\delta G = \sum\delta - \delta P$	δP = 0.467 δG = 2.003
Face Angle of blank	17	Pinion Gear	$\gamma o = \gamma + \delta P$ $\Gamma o = \Gamma + \delta P$	γo=12.51° Гo = 77.57°
Root Angle of blank	18	Pinion Gear	$\gamma R = \gamma - \delta P$ $\Gamma R = \Gamma - \delta P$	γR = 12.2° ГR = 77.1°
Outer Addendum	19	Pinion Gear	$aoP = aP + 0.5F \tan\delta G$ $aoG = aG + 0.5F \tan\delta P$	aoP = 22.54mm aoG=2.80 mm
Outer Dedendum	20	Pinion Gear	$boP = bP + 0.5F \tan\delta P$ $boG = bG + 0.5F \tan\delta G$	boP = 3.08mm boG = 13.56mm
Outer working Depth	21	Both	$hk = aoP + aoG$	hk=25.34 mm
Outer Whole Depth	22	Both	$ht = aoP + boP$	ht=25.62mm
Outside Diameter	23	Pinion Gear	$do = d + 2aoP\ cos\gamma$ $Do = D + 2aoG\ cos$	do=79mm Do=157.21mm

Pitch apex to crown	24	Pinion Gear	$xo = Aocos\gamma - aoP\ sin\gamma$ $Xo = Aocos\Gamma - aoP\ sin\Gamma$	xo=364.14 mm Xo=59.87 mm
Mean diametral Pitch	25	Both	$Pdm = Pd\frac{Ao}{Am}$	Pdm=0.182mm
Mean pitch diameter	26	Pinion Gear	$dm = \frac{n}{Pdm}$ $Dm = \frac{N}{Pdm}$	dm=60.43 mm Dm=274.7 2mm
Thickness factor K	27	Both	Fig.3.17	K=0.3146
Mean normal Circular thickness	28	Pinion Gear	$tn = Pmcos\gamma - Tn$ $Tn = \frac{Pm}{2cos\psi} - (aP - aG)tan\phi + \frac{Kcos\psi}{Pdmtan\phi}$	tn=6.680mm Tn=9.616 mm
Outer normal backlash allowance	29	Both	Table 7	B=0.024
Mean normal Chordal thickness	30	Pinion Gear	$tnc = tn - \frac{t3n}{6d2m} - 0.5B\frac{Am}{Ao}sec\phi$ $Tnc = Tn - \frac{Tn}{6D2m} - 0.5B\frac{Am}{Ao}sec\phi$	tnc=6.654 mm Tnc=9.60 mm
Mean chordaladdendum	31	Pinion Gear	$acP = aP - \frac{t2ncos\gamma}{4dm}$ $acG = aG - \frac{T2ncos\Gamma}{4Dm}$	acP=12.81 mm acG=2.802 mm

Table: 4 Depth Factor

Type of gear	No. pinion teeth	Depth factor k_1
Straight bevel	12 and higher	2.000
Spiral bevel	12 and higher	2.000
	11	1.995
	10	1.975
	9	1.940
	8	1.895
	7	1.835
	6	1.765
Zerol bevel	13 and higher	2.000
Hypoid	11 and higher	4.000
	10	3.900
	9	3.8
	8	3.7
	7	3.6
	6	3.5

Table: 5 Clearance Factors

Type of gear	Clearance factor k_2
Straight bevel	0.140
Spiral bevel	0.125
Zerol bevel	0.110
Hypoid	0.150

Table: 6 Mean Addendum Factor

Type of gear	No. pinion teeth	Mean addendum factor C_1
Straight bevel	12 and higher	C_1†
Spiral bevel	12 and higher	C_1†
	11	0.490
	10	0.435
	9	0.380
	8	0.325
	7	0.270
	6	0.215
Zerol bevel	13 and higher	C_1†
Hypoid	21 and higher	C_1†
	9 to 20	0.170
	8	0.150
	7	0.130
	6	0.110

†Use $C_1 = 0.270 + 0.230/(m_{90})^2$.

Table: 7 Minimum Normal Backlash Allowance

Range of diametral pitch, teeth/in	Allowance, in (for AGMA quality number range) 4 to 9	10 to 13
1.00–1.25	0.032	0.024
1.25–1.50	0.027	0.020
1.50–2.00	0.020	0.015
2.00–2.50	0.016	0.012
2.50–3.00	0.013	0.010
3.00–4.00	0.010	0.008
4.00–5.00	0.008	0.006
5.00–6.00	0.006	0.005
6.00–8.00	0.005	0.004
8.00–10.00	0.004	0.003
10.00–12.00	0.003	0.002
12.00–16.00	0.003	0.002
16.00–20.00	0.002	0.001
20.00–25.00	0.002	0.001

†Measured at outer cone in inches.

3.9 Hypoid Dimensions

The geometry of hypoid gears is complicated by the offset between the axes of the mating members. Therefore a separate set of calculation formulas is needed.

Thestartingdataarethesameasforbevelgearswiththefollowingexceptions:

1. Hypoid offset E is required.

2. Pinion spiral angle ψ_P is specified.

The formulas in Table3.9 are now used to calculate the blank and tooth dimensions

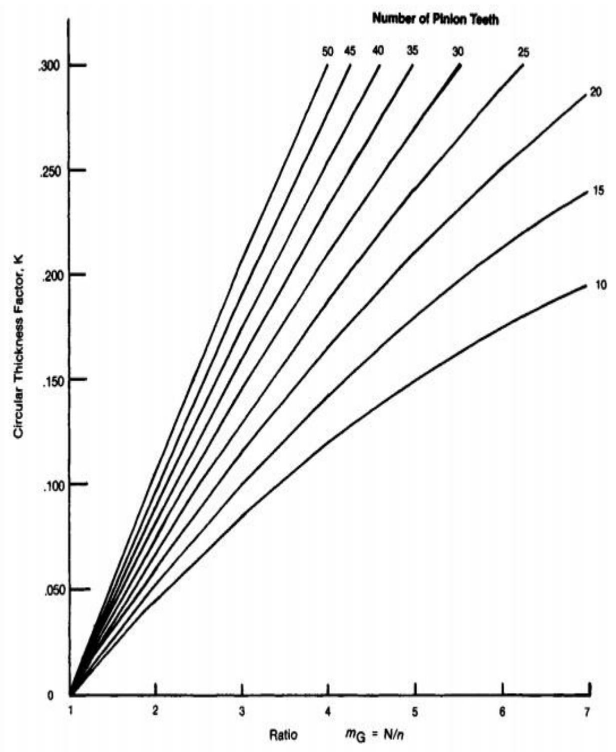

Fig. 6 Circular thickness factor. These curves are plotted from the equation K=-0.08 8 + 0.092m_G - 0.004 m_G^2+0.0016(n-30) (m_G-1)

Table: 8 Formulas for Computing Dedendum Angles and Their Sum

Type of taper	Formula
Standard	$\Sigma\delta = \tan^{-1}\frac{b_P}{A_m} + \tan^{-1}\frac{b_G}{A_m}$ $\delta_P = \tan^{-1}\frac{b_P}{A_m} \quad \delta_G = \Sigma\delta - \delta_P$
Duplex	$\Sigma\delta = \frac{90[1-(A_m/r_c)\sin\psi]}{(P_d A_o \tan\phi \cos\psi)}$ $\delta_P = \frac{a_G}{h}\Sigma\delta \quad \delta_G = \Sigma\delta - \delta_P$
Tilted root line	Use $\Sigma\delta = \frac{90[1-(A_m/r_c)\sin\psi]}{(P_d A_o \tan\phi \cos\psi)}$ or $= 1.3\tan^{-1}\frac{b_P}{A_m} + 1.3\tan^{-1}\frac{b_G}{A_m}$ whichever is smaller. $\delta_P = \frac{a_G}{h} \quad \delta_G = \Sigma\delta - \delta_P$
Uniform depth	$\Sigma\delta = 0$ $\delta_P = \delta_G = 0$

4. Conclusion

In this study, the responses of rear axle are determined under different loading condition and input parameter identified. The mathematical model includes different parameter of Hypoid gear identified.

From the results obtained in the analysis, the following can be concluded:

1) To study basic application and specification of Hypoid Gear. 2) To identified problem in rear axle such as efficiency which used for smooth running of rear axle. 3) To represent design of hypoid for identified different component of rear axle with reference of input parameter of load and out parameter is efficiency of rear axle.4) The analysis performed in this research is based on some assumptions and restrictions. However, complete literature review and input parameter of rear axle identification, thus, understanding of behaviour of rear axle is attained taking every possible detail into account. Therefore, the following are recommended for future work as extensions and elaborations of this research. The calculation and design method should be focused on tooth root strength.

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