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Research Paper

DESIGN AND ANALYSIS OF CROWN PINION OF A DIFFERENTIAL GEAR BOX FOR REDUCED NUMBER OF TEETH TO IMPROVE TORQUE TRANSMITTED

Santosh S Bagewadi[1]*, I G Bhavi[2] and S N Kurbet[3]

Corresponding Author:* ***Santosh S Bagewadi* ✉ *kf.sant@gmail.com*

Bevel gears are widely used because of their suitability towards transferring power between nonparallel shafts at almost any angle or speed. Spiral bevel gears, in comparison to straight or zerol bevel gears, have additional overlapping tooth action which creates a smoother gear mesh. This smooth transmission of power along the gear teeth helps to reduce noise and vibration that increases exponentially at higher speeds. Currently the bolero pickup vehicle of Mahindra Company is running with a pinion present in the differential gear box having 11 numbers of teeth. By reducing number of teeth on pinion, we can increase the torque. So we carried out this work to design a new pinion suitable to fit in the bolero pickup vehicle. Only the number of teeth are reduced by keeping all other dimensions same to fit the new pinion in the same housing.

Keywords: Spiral bevel gear, Pinion, Differential gear box

INTRODUCTION

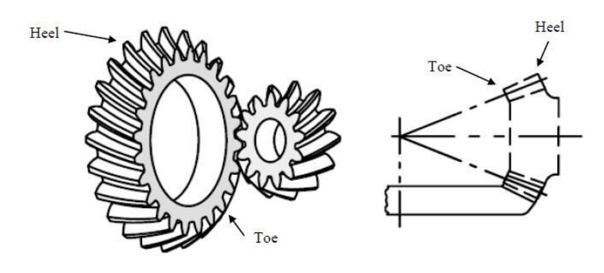
When the car is taking a turn, the outer wheels will have to travel greater speed distance as compared to the inner wheels in the same time, if therefore, the car has a solid rear axle only and no other device, there will be tendency for the wheels to skid. Hence if the wheel skidding is to be avoided, some mechanism must be incorporated in the rear axle, which should reduce the speed of the inner wheels and increase the speed of the outer wheels when taking turns; at the same time it should keep the speed of all the wheels same when going straight ahead. Such a device which serves the above function is called a Differential. In differential gear assembly, crown wheel and pinion are the critical components.

A gear is a mechanical device often used in transmission systems that allows rotational force to be transferred to another gear or device. Throughout the mechanical industry, many types of gears exist with each type of

[1] PG Scholar, Mechanical Department (Machine Design), B.L.D.E.A'S V.P Dr. P.G.H CET, Bijapur, India.
[2] Professor, Automobile, Department (Machine Design), B.L.D.E.A'S V.P Dr. P.G.H CET, Bijapur, India.
[3] Mechanical Department, Basaveshwar Engineering College, Bagalkot, India.

gear possessing specific benefits for its intended applications. Bevel gears are widely used because of their suitability towards transferring power between nonparallel shafts at almost any angle or speed.

Figure 1: Spiral Bevel Gear Mesh



In this work, spiral bevel pinion present in the differential assembly is redesigned. The selected pinion is the existing part of the bolero pickup vehicle. The material used to manufacture the existing pinion is SAE 4130 steel. To provide the same or higher margin of safety to the redesigned pinion, SAE 9310 steel material is chosen.

LITERATURE REVIEW

Matthew D Brown

This paper gives a detailed approach to spiral bevel gear design and analysis. Key design parameters are investigated in accord with industry standards and recommended practices for use in a medium class helicopter. A final gear design is proposed and analyzed to show that proper margins of safety have been included in the design. Upon completion of the design phase of the gear, analysis was conducted to ensure appropriate margins of safety had been implemented into the design. Calculated values of Hertz stress and bending stress are less than the allowable stresses as per AGMA standards. As a result, the stresses produced in the gear teeth were acceptable, mitigating the risk of failure to the designed gear teeth.

S H Gawande et.al

In this paper mechanical design of crown wheel and pinion in differential gear box of MFWD (FWA) Axle (of TAFE MF 455) is done. Detailed modeling, assembly and analysis of tooth of crown gear and pinion is performed in Pro-E. Finite element analysis is performed to analyse the crown gear tooth for working load. Induced equivalent stress is less than allowable stress. From this it is concluded that design is safe.

A Bensely et.al

In this paper failure investigation of crown wheel and pinion has been done. A fractured gear was subjected to detailed analysis using standard metallurgical techniques to identify the cause for failure. The study concludes that the failure is due to the compromise made in raw material composition by the manufacturer, which is evident by the presence of high manganese content and non-existence of nickel and molybdenum. This resulted in high core hardness (458 HV) leading to premature failure of the pinion.

D. Lewicki et.al

An experimental program to test the feasibility of using face gears in a high-speed and high-power environment was conducted. Four face gear sets were tested, two sets at a time, in a closed-loop test stand at pinion rotational speeds to 19,100 rpm and to 271 kW (364 hp). The test gear sets were one-half scale of the helicopter design gear set. Testing the gears at one-eighth power, the test gear set had slightly increased bending and compressive stresses when compared to the full scale design. The tests were performed in the NASA Lewis spiral bevel gear test facility. All four sets of gears successfully ran at 100 percent of design torque and speed for 30 million pinion cycles, and two sets successfully ran at 200 percent of torque for an additional 30 million pinion cycles. The results, although limited, demonstrated the feasibility of using face gears for high-speed, high-load applications.

Robert F Handschuh

Experimental and analytical studies have been conducted with respect to the thermal behavior of spiral bevel gears. The experimental effort was conducted on aerospace quality spiral bevel gears at rotational speeds to 14400 rpm and 537 kW (720 hp). The experimental results indicated that load, jet location, flow rate, and oil inlet temperature all can affect the steady state operating temperature of the spiral bevel pinions that were instrumented. Also an analytical modelling method was developed to analyze the thermal behavior via the finite element method.

MATERIAL SELECTION

The specific application of a gear determines the necessary material properties and additional treatments that may be required. Additional treatments typically considered are through hardening and surface hardening, which includes but is not limited to carburization, nitriding, induction hardening, and flame hardening. Specifically, the desired loading and desired design life are integral in selecting the proper material and any additional treatment that may be required.

Many years of gear industry experience has led the design community to rely on carburized, case-hardened steel for bevel gears. Therefore, spiral bevel gear materials are limited to only those which are easily carburized and case-hardened. Table 1 below, generated from AGMA recommendations of associated steel grades and their typical heat treatments displays the seven potential steel grades which are recognized to be well suited towards carburization in bevel gear applications. To better understand the steel grades above and their metallurgical compositions, Table 2 below shows the common steel designations and their nominal alloy contents.

Table 1: Heat Treatments and Associated Steel Grades

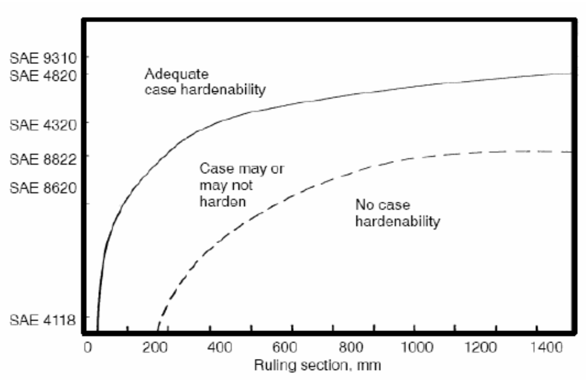
Heat Treatment	Steel Grade
Carburizing	1020
	4118
	4320
	4820
	8620
	8822
	9310
	18CrNiMo7-6

Table 2: Steel Designations and Alloy Contents

Carbon Steels	
10xx	No intentional alloying
15xx	Mn 1.00 - 1.35%
Alloy Steels	
41xx	Cr 1%, Mo 0.25%
43xx	Ni 1.75%, Cr 0.75%, Mo 0.25%
86xx	Ni 0.5%, Cr 0.5%, Mo 0.2%
93xx	Ni 3.25%, Cr 1.25%, Mo 0.12%
Note: "xx" = (nominal percent carbon content x 100)	

Steels under consideration also must have sufficient case hardenability in order to obtain adequate hardness below the depth of the carburized case. Figure 1 below shows the case hardenability for the alloy steels shown in Table 1 and Table.

Figure 2: Case Hardenability of Carburizing Grades of Steel



SAE 9310 will provide the most adequate case hardenability, according to Fig 2, and therefore will be selected as the material from which this pinion will be manufactured.

HEAT TREATMENT

Heat treatment is an operation or combination of operations involving heating at a specific rate, soaking at a temperature for a period of time and cooling at some specified rate. The aim is to obtain a desired microstructure to achieve certain predetermined properties (physical, mechanical, magnetic or electrical).

Heat treatment is considered to be a very important tool of the metallurgist by which he can alter the properties of steel easily. The same steel can have a very wide range of mechanical properties if subjected to different heat treatment. Today, when science and technology are advancing very rapidly in pursuit of higher and higher properties in materials, heat treatment plays a very important role.

In summary, the ultimate goal of a heat treatment procedure is to convert weaker metallurgical grain structures such as pearlite and bainite to a stronger structure like martensite. This process is typically performed using two essential steps; heating the steel to some temperature above its transformation point such that it becomes entirely austenitic in structure, and then quenching the steel at some rate faster than the critical rate in order to produce a martensitic structure. The resulting martensitic structure is mainly dependent on three factors (1) the composition of the alloy (austenite grain size and prior micro-structure), (2) the type and character of the quenching medium (time and temperature during austenitizing), and (3) the size and shape of the specimen. Water, oil and air can be used to increase the rate of cooling, but oil is by far the most effective quenching medium when attempting to form a fully martensitic structure. Geometry and shape of a specimen can also affect the resulting microstructure after quenching, and therefore it is important to investigate the rate at which hardness drops off with distance into the interior of a specimen as a result of diminished martensite content.

DESIGN OF PINION

The process of designing gear teeth is somewhat arbitrary in that the specific application in which the gear will be used determines many of the key design parameters. Recommended design practices are published in the AGMA standard 2005-D03, Design Manual for Bevel Gear Teeth. Spiral angle and pressure angle are two design parameters that help determine the shape of a spiral bevel gear tooth. Common design practices have determined that for spiral bevel gears, a pressure angle of twenty degrees and a spiral angle of thirty five degrees should be used. Following this common practice for selection of spiral angle establishes a good face contact ratio which maximizes smoothness and quietness during gear mesh. In regards to the selection of a pressure angle, a lower pressure angle increases the transverse contact ratio, a benefit which results in increased bending strength, while also increasing the risk of undercut which is a major concern. Lower pressure angles also help to reduce the axial and separating forces and increase the top lands and slot widths.

In addition, spiral bevel gears are designed such that the axial thrust load tends to move the pinion out of mesh. This helps to avoid the loss of backlash, defined as the clearance between mating components. While a lot of backlash is not desirable, small amounts of backlash are required to allow for proper lubrication, manufacturing errors, deflection under load, and differential expansion between the gears and housing.

As previously mentioned, the gear addressed throughout this paper is replacing a similar gear that operated in the fleet for many years. The main difference between the two gears is the number of teeth on the pinion which helps to achieve the proper gear reduction ratio. Minimal changes were made to the values for diametral pitch, pitch diameter, pitch angles, and face width, which are the basis for calculating the necessary geometric design parameters.

LOADING

Torque application to a spiral bevel gear mesh induces tangential, radial, and separating loads on the gear teeth. For simplicity, these loads are assumed to act as point loads applied at the mid-point of the face width of the gear tooth. The radial and separating loads are dependent upon the direction of rotation and hand of spiral, in addition to pressure angle, spiral angle and pitch angle. The tangential loads are defined as

$$Wtp = \frac{2\ Tp}{dp - F \sin \gamma}$$

for the pinion with T equal to the torque, dp equal to the pitch diameter, F equal to the face width, γ equal to the pitch angle of the pinion.

The radial and separating loads are calculated as a percentage of the tangential loads calculated above. For a right hand of spiral rotating counter clockwise, the axial thrust load for a driving member (pinion) is defined as

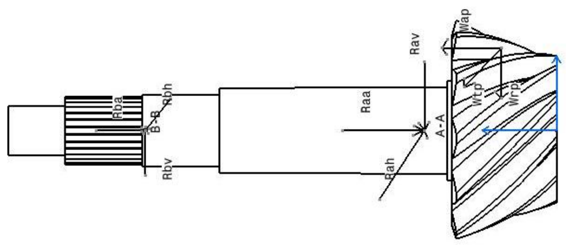
$$Wa = \frac{Wtp}{\cos \psi} (\tan\phi \sin\gamma + \sin\psi \cos\gamma$$

And the separating load is defined as,

$$Wr = \frac{Wtp}{\cos \psi} (\tan\phi \cos\gamma - \sin\psi \sin\gamma$$

Where ϕ is the pressure angle and ψ is the mean spiral angle. Figure 2 below displays the line of action through which the tangential, axial and separating loads act.

Figure 3: Loads Acting on Pinion



The loads in Figure 3, labeled Rba, Rbh, Rbv, Raa, Rav, and Rah, are reaction loads generated by the two tapered roller bearings that support the gear shaft. It is the responsibility of these bearing reaction loads to counteract the forces generated by the mesh of the gear teeth, shown in the fig 2 as *Wap*, *Wtp* and *Wrp*.

ANALYTICAL METHODOLOGY

Spiral bevel gear teeth are primarily designed for resistance to pitting and for their bending strength capacity. Design for pitting resistance is primarily governed by a failure mode of fatigue on the surface of the gear teeth under the influence of the contact stress between the mating gears. Design for bending strength capacity is based on a failure mode of breakage in the gear teeth caused by bending fatigue.

The basic equation for compressive stress in a bevel gear tooth is given by

$$fc = Cp\sqrt{\frac{WtxCox1xKm}{CvxFxdpx1}}$$

Where *Cp* is the elastic coefficient, *Wt* is the tangential tooth load, *Co* is the overload factor, *Cv* is the dynamic factor, *F* is the face width, *dp* is the pitch diameter, *Km* is the load distribution factor, and I *is* the geometry factor.

Bending strength capacity ratings in bevel gear teeth are developed using a simplified approach to cantilever beam theory. Calculating the bending strength rating will determine the acceptable load rating at which tooth root fillet fracture should not occur during the entirety of the life of the gear teeth under normal operation.

The basic equation for bending stress in a bevel gear is given by

$$fb = Wtp\ \frac{PITCHx\ KsxKm}{Fxj}$$

where *Wt* is the tangential tooth load previously discussed, *PITCH* is the diametral pitch, *F* is the face width, *Ks* is the size factor, *Km* is the load distribution factor, and j is the geometry factor. Finally fatigue margin of safety, M.S, can be calculated using the formula.

$$M.S. = \frac{F_{en}}{Kt\ xf_b}$$

Where F_{en} is the endurance limit

CONCLUSION

Currently the existing pinion is manufactured by SAE 4130 steel material. The existing bevel pinion is redesigned by considering SAE 9310 steel as the pinion material. Decrease in the number of teeth on pinion leads to the increase in torque at the output. Calculating the design parameters for SAE 4130 steel material gives the margin of safety value of 0.57 for 11 teeth. Similar calculations are done for SAE 9310 steel material which gives margin of safety value of 0.68 for 10 teeth. From this we can conclude that margin of safety is high even though after reducing 1 tooth on pinion. Reduction of teeth also reduces the weight of the pinion. So the newly designed pinion can be installed in the existing gear box with the existing bearing, housing and other accessories.

REFERENCES

1. A Bensely, S Stephen Jayakumar, D Mohan Lal, G Nagarajan and A Rajadurai (2006), “Failure Investigation of Crown Wheel and Pinion”, *Engineering Failure Analysis*, Vol. 13, pp. 1285–1292.
2. Askeland, Donald R and Pradeep P Fulay (2005), “The Science and Engineering of Materials. New York: Cengage Engineering”.
3. Callister, William D Jr (2003), “Materials Science and Engineering an Introduction”, *New York: John Wiley & Sons Inc*.
4. G González Rey, R J García Martín and P Frechilla Fernández (2007), “Estimating Gear Fatigue Life Using the Strength-life Theory”, *Gear Solutions*.
5. Hemanshu D Joshi, K D Kothari (2014), “Mode and Cause of Failure of a Bevel gear-A Review”, *International Journal of Advance Engineering and Research Development (IJAERD*, Vol. 1, No. 2, pp. 2348-4470.
6. Horton, Holbrook L, Franklin D Jones, Erik Oberg and Henry H Ryffel (2008), *Machinery’s Handbook, 28th Edition. New York: Industrial Press*.
7. Matthew D Brown (2009), “Design and Analysis of a Spiral Bevel Gear”, *Rensselaer Polytechnic Institute Hartford, Connecticut*.
8. R Handschuh, D Lewicki and R Bossier (1992), “Experimental Testing of Prototype Face Gears for Helicopter Transmissions”, *NASA Technical Memorandum 105434, Prepared for Gcearbox Configurations of the 90’s, sponsored by the Institute of Mechanical Engineers, Solihull, West Midlands, United Kingdom*.
9. Robert F Handschuh and Thomas P Kicher (1995), “Experimental and Analytical Assessment of the Thermal Behavior of Spiral Bevel Gears”, *Prepared for the 1995 Fall Technical Meeting, sponsored by the American Gear Manufacturers Association, Charleston, South Carolina*, pp. 16-18.
10. S H Gawande, S V Khandagale, V T Jadhav, V D Patil and D J Thorat (2013), “Design, Manufacturing & Analysis of Differential Crown Gear and Pinion for MFWD Axle”, *(Department of Mechanical Engineering, M.E.S. College of Engineering, Pune)*.