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Impact of Misalignments on Root Stresses of Hypoid Gear Sets using Ansys

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ABSTRACT

In this study, the impact of misalignments on root stresses of hypoid gear sets is investigated numerically and theoretically. By taking experimental values of an experimental setup designed to allow operation of a hypoid gear pair under loaded quasi-static conditions with various types of tightly controlled misalignments is introduced. These misalignments include the position errors (V and H) of the pinion along the vertical and horizontal directions, the position error (G) of the gear along its axis, and the angle error (γ) between the two gear axes. A computational model is also proposed to predict the root stresses of face-milled and face- hobbed hypoid gear pairs under various loading and misalignment conditions.

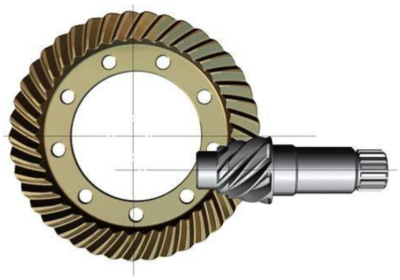
The model employs an automated finite elements mesh generator based on a predefined template for a general and computationally efficient treatment of the problem. The impact of misalignments on root stresses of hypoid gear sets is investigated theoretically with FEA. Structural analysis is done to verify the strength of the hypoid gear for alignment and misalignment. Software for modeling is CATIAV5 and for analysis is ANSYS.

INTRODUCTION

Gears are toothed wheels, which have been used for about 3000 years. It was invented to transmit circular motion and rotational force from one part to another in mechanical machines. Today, gears are used in many machinery systems with various range of sizes and materials. It is practically used in pairs by attaching them to a shaft. When the two gears are meshed, rotation from the drive gear called pinion causes the driven gear called wheel to rotate and transmit power. The classification of gear pair is according to their relative positions on the axis of revolution, where the intersection between the parallel or non-parallel gear's tooth mesh takes place. The gears that have parallel shafts are spur, helical and herringbone gears; while the non- parallel shafts are bevel and spiral gears.

WHAT IS A HYPOID GEAR

A Hypoid Gear is a spiral bevel gear whose main variance is that the mating gears axes do not intersect. The hypoid gear is offset from the gear centre, allowing unique configurations and a large diameter shaft. The teeth on a hypoid gear are helical, and the pitch surface is best described as a HYPERBOLOID.



Brief History

Hypoid Gears were developed by the American Gleason company for driving rear axles of automobiles in 1925. It is still mainly used for cars. A Hypoid gear is used when the included angle is square and the distance between the axes is relatively small. The hypoid gear is viewed as an intermediate between a bevel gear and a worm gear machine.

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They are cone shaped gears similar to spiral bevel gears except they transmit motion between non-intersecting shafts. The smaller gear shaft (hypoid pinion side) is offset from the larger gear shaft (hypoid gear side). Given the proper offset amount, the pinion shaft and the larger gear shaft can pass each other without interference, enabling the shafts to be supported securely on both sides.

Gear Nomenclature

Addendum: The radial distance between the Pitch Circle and the top of the teeth.

Arc of Action: Is the arc of the Pitch Circle between the beginning and the end of the engagement of a given pair of teeth.

Arc of Approach: Is the arc of the Pitch Circle between the first point of contact of the gear teeth and the Pitch Point.

Arc of Recession: That arc of the Pitch Circle between the Pitch Point and the last point of contact of the gear teeth.

Base Circle: The circle from which is generated the involute curve upon which the tooth profile is based.

Center Distance: The distance between centers of two gears.

Circular Pitch: Millimetre of Pitch Circle circumference per tooth.

Circular Thickness: The thickness of the tooth measured along an arc following the Pitch Circle

Clearance: The distance between the top of a tooth and the bottom of the space into which it fits on the meshing gear.

Contact Ratio: The ratio of the length of the Arc of Action to the Circular Pitch.

Dedendum: The radial distance between the bottom of the tooth to pitch circle.

Diametral Pitch: Teeth per mm of diameter.

Face: The working surface of a gear tooth, located between the pitch diameter and the top of the tooth.

Face Width: The width of the tooth measured parallel to the gear axis.

Flank: The working surface of a gear tooth, located between the pitch diameter and the bottom of the teeth

Wheel: Larger of the two meshing gears is called wheel..

Pinion: The smaller of the two meshing gears is called pinion.

Land: The top surface of the tooth.

Line of Action: That line along which the point of contact between gear teeth travels, between the first point of contact and the last.

Module: Ratio of Pitch Diameter to the number of teeth..

Pitch Circle: The circle, the radius of which is equal to the distance from the center of the gear to the pitch point.

Diametral pitch: Ratio of the number of teeth to the of pitch circle diameter.

Pitch Point: The point of tangency of the pitch circles of two meshing gears, where the Line of Centers crosses the pitch circles.

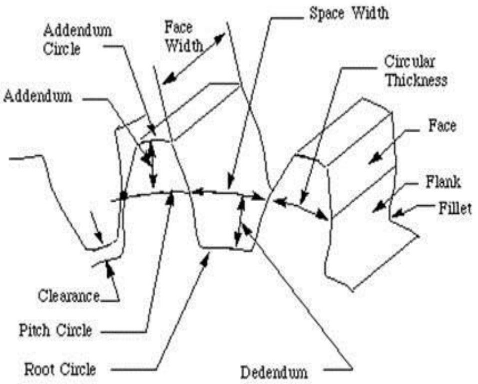
Pressure Angle: Angle between the Line of Action and a line perpendicular to the Line of Centers.

Ratio: Ratio of the numbers of teeth on mating gears.

Root Circle: The circle that passes through the bottom of the tooth spaces.

Root Diameter: The diameter of the Root Circle.

Working Depth: The depth to which a tooth extends into the space between teeth on the mating gear



Hypoid Gear Operation

Hypoid gears have a large pitch surface with multiple points of contact. They can transfer energy at nearly any angle. Hypoid gears have large pinion diameters and are useful in torque-demanding applications. The heavy work load expressed through multiple sliding gear teeth means hypoid gears need to be well lubricated, but this also provides quiet operation and additional durability.

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Materials Used

Gear composition is determined by application, including the gear's service, rotation speed, accuracy and more.

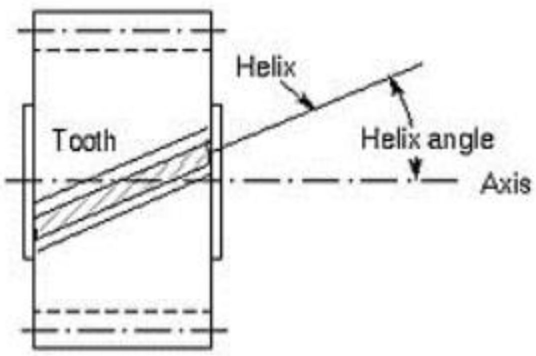
Cast iron provides durability and ease of manufacture.
Alloy steel provides superior durability and corrosion resistance. Minerals may be added to the alloy to further harden the gear.
Cast steel provides easier fabrication, strong working loads and vibration resistance.
Carbon steels are inexpensive and strong, but are susceptible to corrosion.
Aluminium is used when low gear inertia with some resiliency is required.
Brass is inexpensive, easy to mould and corrosion resistant.
Copper is easily shaped, conductive and corrosion resistant. The gear's strength would increase if bronzed.
Plastic is inexpensive, corrosion resistant, quiet operationally and can overcome missing teeth or misalignment. Plastic is less robust than metal and is vulnerable to temperature changes and chemical corrosion. Acetal, delrin, nylon, and polycarbonate plastics are common.
Other material types like wood may be suitable for individual applications

Specifications

Hypoid gears are common in truck drive differentials, where high torque and an offset pinion are valued. However, an offset pinion does expend some mechanical efficiency. Hypoid gears are very strong and can offer a large gear reduction. Due to their exclusive arrangement, hypoid gears are typically produced in opposite-hand pairs (left and right handedness).

Dimension Specifications

Gears mate via teeth with very specific geometry. Pressure angle is the angle of tooth drive action, or the angle between the line of force between meshing teeth and the tangent to the pitch circle at the point of mesh. Typical pressure angles are 14.5° or 20°, but hypoid sometimes operate at 25°. Helix angle is the angle at which the gear teeth are aligned compared to the axis



Advantages

1. Hypoid gears are stronger, operate more quietly and can be used for higher reduction ratios, however they also have some sliding action along the teeth, which reduces mechanical efficiency, the energy losses being in the form of heat produced in the gear surfaces and the lubricating fluid.
2. In older automotive designs, hypoid gears were typically used in rear-drive automobile drivetrains, but modern designs have tended to substitute spiral bevel gears to increase driving efficiency.
3. Hypoid gears are still common in larger trucks because they can transmit higher torque. A higher hypoid offset allows the gear to transmit higher torque. However increasing the hypoid offset results in reduction of mechanical efficiency and a consequent reduction in fuel economy. For practical purposes, it is often impossible to replace low efficiency hypoid gears with more efficient spiral bevel gears in automotive use because the spiral bevel gear would need a much larger diameter to transmit the same torque. Increasing the size of the drive axle gear would require an increase of the size of the gear housing and a reduction in the ground clearance.
4. Another advantage of hypoid gear is that the ring gear of the differential and the input pinion gear are both hypoid. In most passenger cars this allows the pinion to be offset to the bottom of the crown wheel. This provides for longer tooth contact and allows the shaft that drives the pinion to be lowered, reducing the

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"hump" intrusion in the passenger compartment floor. However, the greater the displacement of the input shaft axis from the crown wheel axis, the lower the mechanical efficiency

Disadvantages

1. Less efficiency because of sliding
2. Low availability
3. More vulnerable to lubrication problems because of sliding action

Applications

1. These gears are usually used in industrial and automotive application and hence the material used is a metal like stainless steel.
2. A major application of hypoid gears is in car differentials where the axes of engine and crown wheel are in different planes.
3. Hypoid gears are critical components of various power train systems.
4. They find their most common applications in automotive drive trains, heavy truck, and off-highway vehicle transmissions as well as industrial gearboxes.
5. Hypoid gears provide one of the most reliable ways of transmitting power between two nonintersecting shafts at usually a right angle from each other.

MISALIGNMENTS

Misalignment is probably the most common, single cause of failure. Due to misalignment, the pinion does not mesh properly with the gear during operation, and this leads to a high stress concentration at the surface and root of the gear teeth. Misalignment suggests a shifting of the theoretical position of pinion to wheel engagement from the actual position had happened when the gear pair is in their meshing position. Several known causes of misalignments are due to deflection, errors during manufacture or assembly of the gear pair, or various other parameters. The occurrence of any of these actions typically alters the location of active contact face width directly to the tooth flank, which leads to undistributed large stresses. Hence, it may also increase the noise and vibration of the gear system. Misalignment in between spur gear teeth can occur in many forms and variants, but basically, it may be divided into three categories relatively to their coordinate of Line of Action.

CATIA V5

CATIA is an acronym for Computer Aided Three-dimensional Interactive Application. It is one of the leading 3D software used by organizations in multiple industries ranging from aerospace, automobile to consumer products.

CATIA is a multi platform 3D software suite developed by Dassault Systems, encompassing CAD, CAM as well as CAE. Dassault is a French engineering giant active in the field of aviation, 3D design, 3D digital mock-ups, and product lifecycle management (PLM) software. CATIA is a solid modelling tool that unites the 3D parametric features with 2D tools and also addresses every design-to-manufacturing process. In addition to creating solid models and assemblies, CATIA also provides generating orthographic, section, auxiliary, isometric or detailed 2D drawing views.

It is also possible to generate model dimensions and create reference dimensions in the drawing views. The bi-directionally associative property of CATIA ensures that the modifications made in the model are reflected in the drawing views and vice-versa.

ANSYS 16.0

ANSYS is one those tools which are currently used with a lot of applications which have significant impacts on our daily life.

Founded in 1970 by Dr. John A. Swanson as Swanson Analysis Systems, Inc. SASI. Its primary purpose was to develop and market finite element analysis software for structural physics that could simulate:
Static (stationary)

Dynamic (moving)

Thermal (heat transfer) problems.

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ANSYS (Analysis System) is a brilliant software used for very complex and crucial analysis which are playing vital roles in today's engineering.

Basically it is an engineering simulation software. This special software has no parallel application that could stand beside it.

ANSYS has two major dimensions.
Simulation Technology:
1. Structural Mechanics
2. Multiphysics
3. Fluid Dynamics
4. Explicit Dynamics
5. Electromagnetics
6. Hydrodynamics (AQWA).

Workflow Technology:

- ANSYS workbench platform
- High-Performance Computing
- Geometry Interfaces
- Simulation Process and Data Management

OVERVIEW OF THE PROJECT

Misalignment in Hypoid Gears
Misalignments are the deviations of the gears forming the pair from their ideal positions relative to each other.

They are normally caused by manufacturing errors of the housing, gears, and shafts. Misalignments can alter the load distributions and consequently the strain distributions along the roots of hypoid gears. The main focus of this paper is on numerical and analytical investigation of the effect of misalignments on the hypoid gear root stresses.

Literature Review

The forces acting on the hypoid gear are calculated theoretically. Structural analysis and Modal analysis are done on the designed models to verify the stresses developed. The materials used are Steel, Aluminium Alloy, Cast Iron and Titanium. Analysis is done by using ANSYS.

By observing the analysis results, the stresses are increased when the gears are misaligned. So it can be concluded that due to misalignment there is an increase in stress on the tooth root thereby probably could lead to a fatigue initiation at the maximum stress region and finally leads to breakage of the gear.

Scope and Objectives

The research is conducted in order to study the impact of misalignments on root stresses of hypoid gears that are manufactured using different materials and to check the results of percentage of increase in stress and the change in strain, deformation and pressure when there is a misalignment of about 5%.

The main objectives of the study are

- Calculate the forces acting on hypoid gears theoretically.
- Design hypoid gear sets in CATIA V5 under the conditions of both alignment and misalignment.
- Structural Analysis of the hypoid gear sets using ANSYS16.0

NUMERICAL ANALYSIS AND DESIGN

Calculation of forces acting on hypoid gears
There are three forces that act on the gear teeth in contact - tangential, axial and radial force. The axial and the radial forces are dependent on the curvature of the loaded tooth face.

Tangential force: The tangential force on the gear (larger element or the one with more number of teeth) is given by the following equation

$$W_{tG} = \frac{2T_G}{D_m}$$

Pinion hand of spiral	Rotation of driver	Loaded face	
		Driver	*Driven*
Right	clockwise	convex	concave
	counterclockwise	concave	convex
Left	clockwise	concave	convex
	counterclockwise	convex	concave

Table 1

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Where TG is the torque transmitted by the gear (Nm) and Dm is the mean pitch diameter (m) of the gear. The tangential force on the pinion is given by

$$W_{tP} = \frac{2T_P}{d_m}$$

Where T_P is the torque transmitted by the pinion (Nm) and d_m is the mean pitch diameter (m) of the pinion.

Radial force: The radial forces on the ring gear/pinion depend on which face is the loaded face. If the loaded face is the concave face, then the radial force can be computed by

$$W_r = \frac{W_t}{cos(\psi)}[tan(\phi)cos(\gamma) - sin(\psi)sin(\gamma)]$$

If, the loaded face is the convex face, then the radial force can be computed using

$$W_r = \frac{W_t}{cos(\psi)}[tan(\phi)cos(\gamma) + sin(\psi)sin(\gamma)]$$

– Wr is the radial force on the corresponding gear element
– Wt is the tangential force on the corresponding gear element
– Y is the mean spiral angle at pitch surface of the corresponding gear element
– γ is the pitch angle of the corresponding gear element

In the above equations the parameters of the corresponding gear element - ring gear or pinion can be plugged in, in order to obtain the radial force. If the radial force has a positive sign (+), then it indicates that the force is acting away from the mating member and this force is termed as separating force. Alternatively, a negative sign (−) indicates the direction of force is towards the mating member and is termed as attracting force.

Axial Force: The axial forces on the ring gear/pinion also depend on which face is the loaded face. If the loaded face is the concave face, then the axial force can be computed by

$$W_x = \frac{W_t}{cos(\psi)}[tan(\phi)sin(\gamma) + sin(\psi)cos(\gamma)]$$

If, the loaded face is the convex face, then the axial force can be computed using

$$W_x = \frac{W_t}{cos(\psi)}[tan(\phi)sin(\gamma) - sin(\psi)cos(\gamma)]$$

– Wx is the axial force on the corresponding gear element
– Wt is the tangential force on the corresponding gear element
– ψ is the mean spiral angle at pitch surface of the corresponding gear element
– γ is the pitch angle of the corresponding gear element

In above equations the parameters of the corresponding gear element - ring gear or pinion can be plugged in, in order to obtain the axial force. A positive sign (+) is indicative of the fact that the thrust is acting away from the pitch apex [4]. Alternatively, a negative sign (−) indicates that the thrust is acting towards the pitch apex.

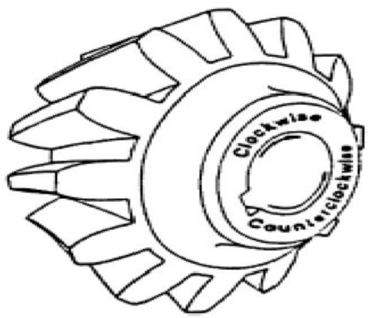
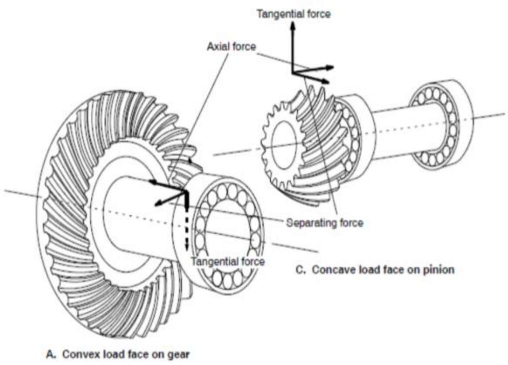


Fig Determining the direction of forces



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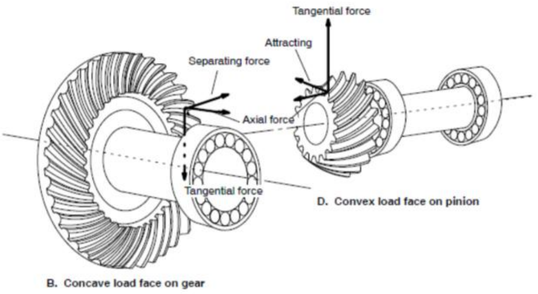

Forces acting on hypoid gear

Calculation of load acting on hypoid gear

The forces acting on the meshing point of the hypoid gear is as follows

$$P_1 = \frac{9\ 550\ 000H}{n_1\left(\frac{D_{m1}}{2}\right)} = \frac{\cos\beta_1}{\cos\beta_2} P_2 \ \cdots\cdots\cdots\cdots\cdots\ \text{(N)}$$

$$= \frac{974\ 000H}{n_1\left(\frac{D_{m1}}{2}\right)} = \frac{\cos\beta_1}{\cos\beta_2} P_2 \ \cdots\cdots\cdots\cdots\cdots\ \{\text{kgf}\}$$

$$P_2 = \frac{9\ 550\ 000H}{n_2\left(\frac{D_{m2}}{2}\right)} \ \cdots\cdots\cdots\cdots\cdots\ \text{(N)}$$

$$= \frac{974\ 000H}{n_2\left(\frac{D_{m2}}{2}\right)} \ \cdots\cdots\cdots\cdots\cdots\ \{\text{kgf}\}$$

$$D_{m1} = D_{m2}\frac{z_1}{z_2} \cdot \frac{\cos\beta_1}{\cos\beta_2}$$

$$D_{m2} = d_{p2} - w_2 \sin\delta_2$$

Where

H= Transmitted Power

D_{m1}= Average pitch diameter of pinion (mm)

D_{m2}= Average pitch diameter of gear (mm)

N= Speed in rpm

Z_1= Number of teeth on pinion

Z_2= Number of teeth on gear

d_p= Pitch diamter(mm)

The input parameters by which the load is calculated and the hypoid gear set is designed is referred froms

Parameter name	Symbol	Value	Parameter name	Symbol	Value
Shaft angle	Σ	90 °	Number of teeth pinion	z_1	13
Hypoid offset	a	24 mm	Number of teeth wheel	z_2	36
Pressure angle	a_{mn}	20 °	Mean spiral angle pinion	β_{m1}	45 °59'
Normal module	m_{mn}	3.3842 mm	Face width tooth wheel	b_2	30 mm
Gear ratio	i	2.769	Outer pitch diameter wheel	d_{e2}	165 mm
Addendum modification coef.	$x_{hm1} = -x_{hm2}$	0	Blade groups	z_0	11
Basic crown gear addendum factor	k_{hap}	1	Cutter radius	r_{c0}	63.5 mm
Basic crown gear dedendum factor	k_{hfp}	1.25	Thickness modification coefficient	x_{smn}	0
Addendum angle of wheel	θ_{a2}	1.5 °	Pinion speed	n_1	4500 rpm
Dedendum angle of wheel	θ_{f2}	-1.5 °	Sense of pinion		Right
Driving member		Pinion	Driving flank		Concave
Wheel cutting method		Formate	Cutting method		Face Hobbing

Table 2

Parameter name	Symbol	Pinion	Wheel
Mean diameter	d_{0m}	63.32 mm	137.47 mm
Mean Spiral Angle wheel	β_{m2}	***See table 2***	27 °36'
Pitch angle	δ	29 °10'	59 °32'
Face width tooth	b	33.78 mm	***See table 2***
Addendum	h_{km}	3.3845 mm	3.3845 mm
Dedendum	h_{fm}	4.06 mm	4.06 mm
Outer pitch cone distance	R_e	82.8397 mm	95.7169 mm
Crown gear to cutter centre distance (base circle)	$\rho_{P0} = E_x$	65.2705 mm	92.4075 mm
Epicycloid roll circle radius	$\rho_{P0} - \rho_b = E_b$	19.0589 mm	19.2636 mm

Table 3

From the given data we get

Average pitch diameter of gear is

D_{m2}= 165-(30)sin(59°32')

= 139.199 mm

Average pitch diameter of pinion is

D_{m1}= (139.199)(13/36)(cos 45°59'/cos 27°36')

= 39.61 mm

H= Transmitted Power (KW)

H= (2PNT)/60

=47.61KW

Force acting on pinion

P1=5100.61N

Force acting on gear

P2=6477.77N

Materials used for gears and their properties

The materials used for the analysis of gears in this paper are steel, aluminium, cast iron and titanium.

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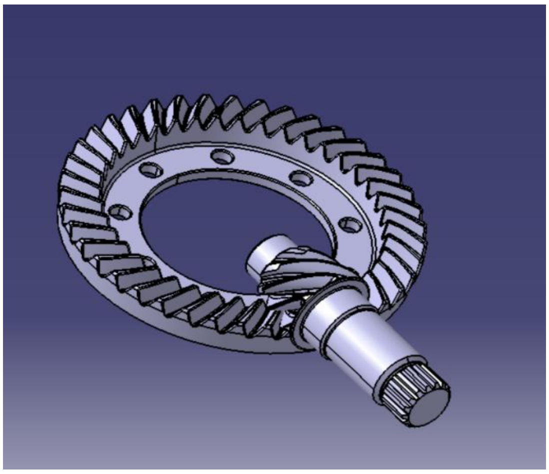
Material Used	Density	Young's Modulus	Poissons Ratio
Aluminium	2,710	70-80	0.33
Steel	7,800	200	0.26
Cast Iron			
Titanium			

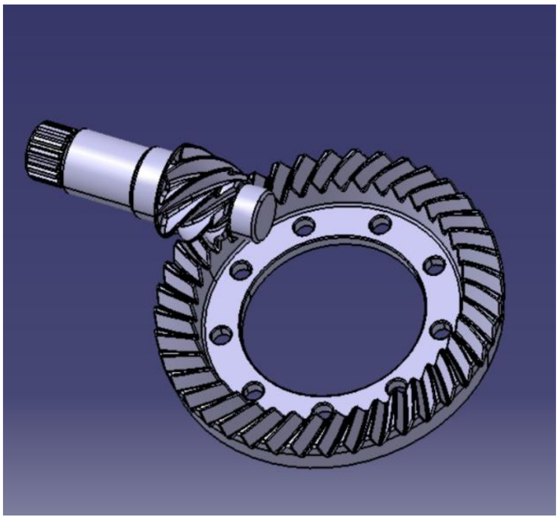
Design of Hypoid Gear in CATIA V5

A model is generated using CATIA software and then it is retrieved into ANSYS using IGES files. Hypoid gear with the given parameters is drawn using CATIA V5 software under the conditions of alignment and misalignment.

Perfectly aligned hypoid gear

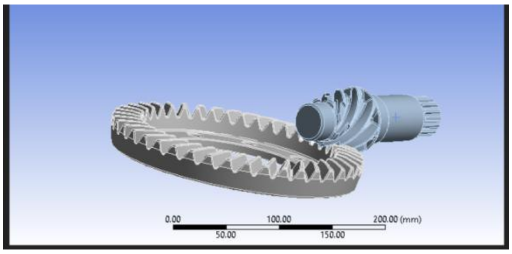


Misaligned hypoid gear

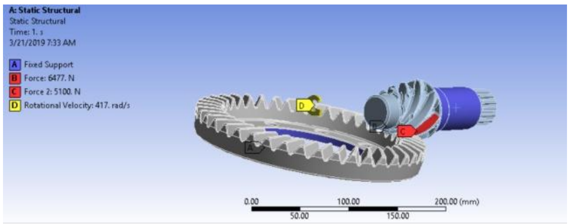


ANALYSIS OF HYPOID GEARS USING ANSYS

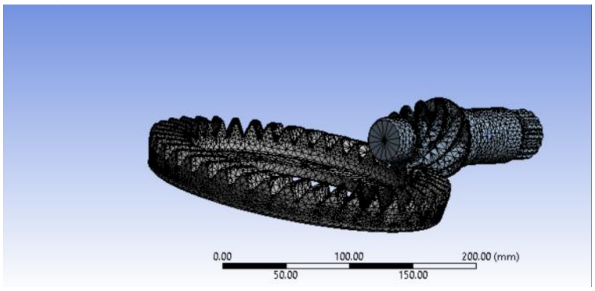
The design model of hypoid gears in alignment and misalignment which are in the form of .stp or .iges are imported from CATIA V5 to ANSYS.



Load calculated from the parameters are applied on the model



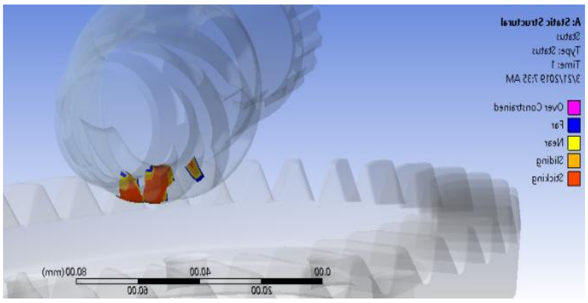
Fine tetrahedral mesh is applied for the given set of hypoid gears



Number of nodes=172774
Number of elements=100504

Analysis Of Perfectly Aligned Hypoid Gears Made Of Steel

Contact in between the gears when perfectly aligned



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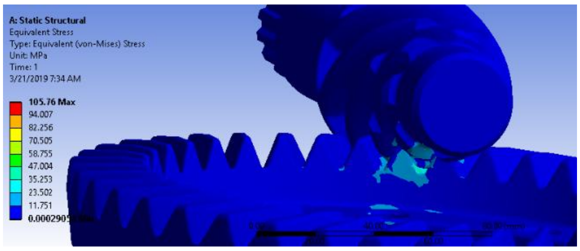
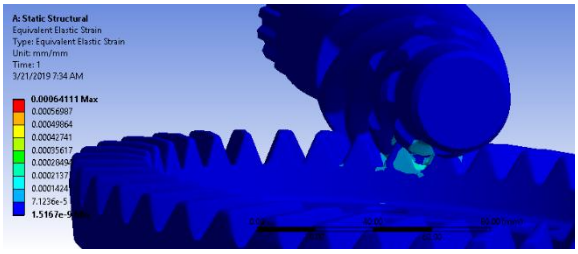
Stress



Maximum stress=105.76MPa

Minimum stress=0.00029058MPa

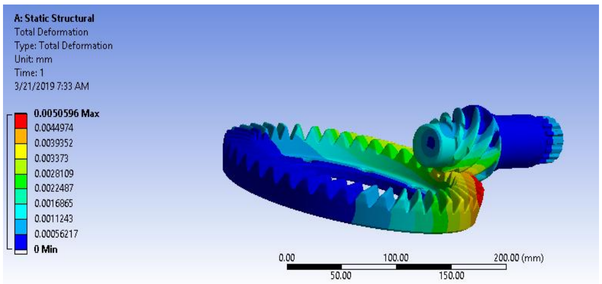
Strain analysis



Maximum Strain=0.00064111

Minimum Strain=1.5167e^{-9}

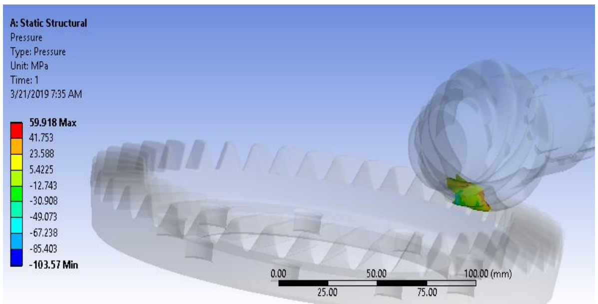
Total Deformation



Maximum Deformation=0.0050596mm

Minimum Deformation=0mm

Pressure

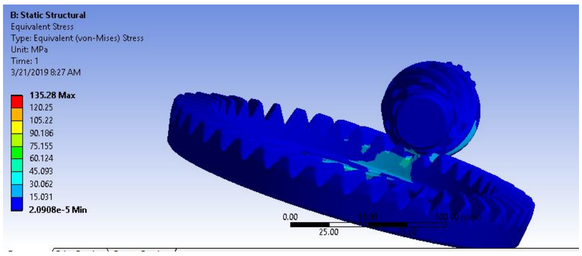


Maximum Pressure=59.918MPa

Minimum Pressure= -103.57MPa

Analysis Of Misaligned Hypoid Gears Made Of Cast Iron

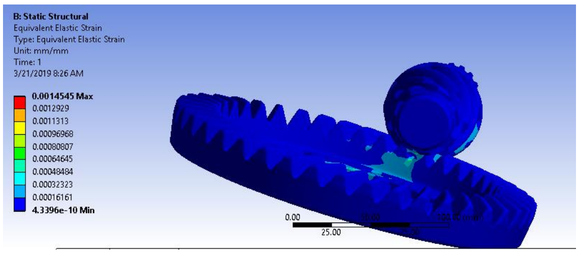
Stress



Maximum Stress=135.28MPa

Minimum Stress=2.0908e^{-5}

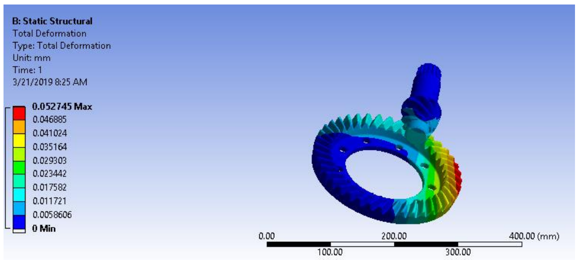
Strain



Maximum Strain=0.0014545

Minimum Strain=4.3396e^{-10}

Total Deformation

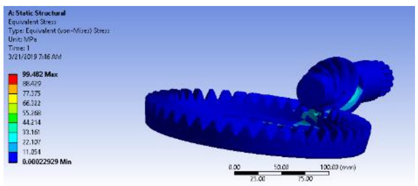


Maximum Deformation=0.052745mm

Minimum Deformation=0mm

Analysis Of Perfectly Aligned Hypoid Gears Made Of Titanium

Stress



Maximum Stress=99.482MPa

Minimum Stress=0.00022929MPa

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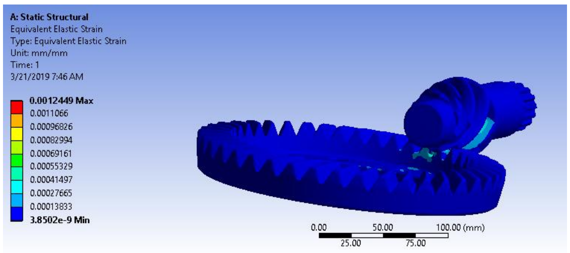
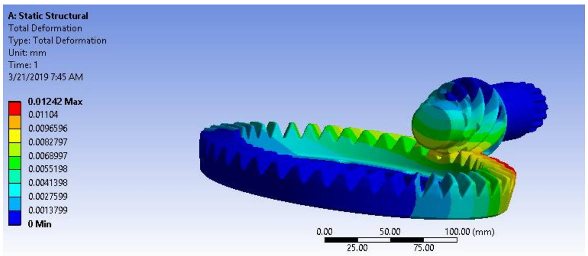
Strain



Maximum Strain=0.0012449
Minimum Strain=$3.8502e^{-9}$

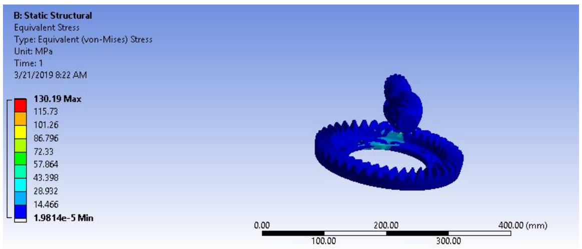
Total Deformation



Maximum Deformation=0.01242mm
Minimum Deformation=0mm

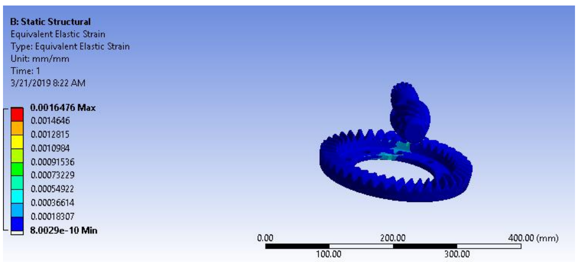
Analysis Of Misaligned Hypoid Gears Made Of Titanium

Stress



Maximum Stress=130.19MPa
Minimum Stress=$1.9814e^{-5}$MPa

Strain



Maximum Strain=0.0016476
Minimum strain=$8.0029e^{-10}$

RESULTS

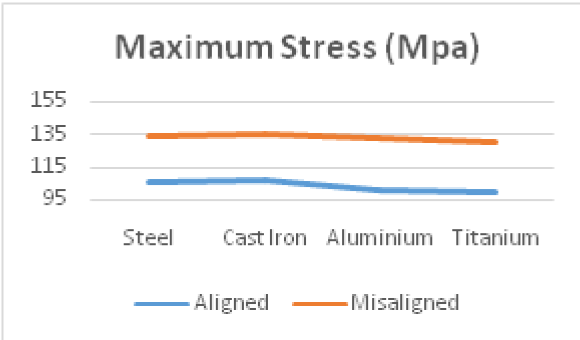
The result from the analysis of hypoid gear sets using ansys are tabulated below

Material Used		Stress (Mpa)		Strain		Deformation (mm)		Pressure (Mpa)	
		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Steel	Aligned	105.76	0.00029058	0.000641	1.5167 E-09	0.00506	0	59.918	-103.57
	Misaligned	134.1	0.000020672	0.000792	2.5859 E-10	0.028948	0	63.957	-111.99
Cast Iron	Aligned	106.73	0.00027819	0.001177	2.6517 E-09	0.009541	0	60.834	-106.29
	Misaligned	135.28	0.000020908	0.001455	4.3396 E-10	0.052745	0	65.334	-111.76
Aluminium	Aligned	101.11	0.00021758	0.001714	4.8158 E-09	0.018367	0	68.355	-143.89
	Misaligned	132.23	0.000016058	0.002216	9.2745 E-10	0.0811	0	61.272	-112.46
Titanium	Aligned	99.482	0.00022929	0.001245	3.8502 E-09	0.01242	0	65.729	-134.23
	Misaligned	130.19	0.000019814	0.001648	8.0029 E-10	0.059632	0	57.772	-113.26

Table 5 Results of Hypoid gears

Material Used	Maximum Stress (Mpa)	
	Aligned	Misaligned
Steel	105.76	134.1
Cast Iron	106.73	135.28
Aluminium	101.11	132.23
Titanium	99.482	130.19

Table 6 Maximum Stress for the hypoid gear sets



Graph1 Material Used Vs Maximum stress

The above graph is drawn between the materials used for the hypoid gear sets Vs Maximum stress for the conditions of alignment and misalignment. The percentage increase in stress during misalignment for the materials used is as follows

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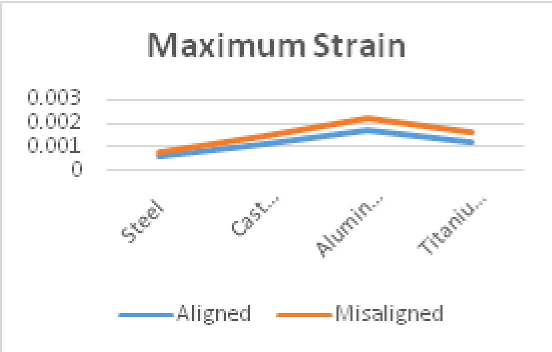
For steel %increase in stress= 26.79%
For Cast Iron %increase in stress=26.74%
For Aluminium %increase in stress=30.77%
For Titanium %increase in stress=30.87%

Material Used	Maximum Strain	
	Aligned	**Misaligned**
Steel	0.00064111	0.00079236
Cast Iron	0.0011771	0.0014545
Aluminium	0.0017138	0.0022159
Titanium	0.0012449	0.0016476

Table 7 Maximum Strain for the Hypoid Gear sets

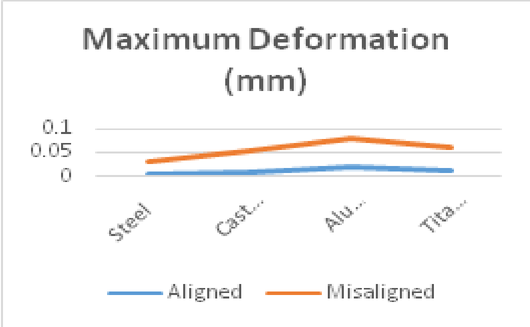


Graph 2 Materials Used Vs Maximum strain

The above graph is drawn between the materials used for the hypoid gear sets Vs Maximum strain for the conditions of alignment and misalignment. The percentage increase in strain during misalignment for the materials used is as follows
For steel %increase in strain= 23.59%
For Cast Iron %increase in strain=23.56%
For Aluminium %increase in strain=29.29%
For Titanium %increase in strain=32.3%

Material Used	Maximum Deformation (mm)	
	Aligned	**Misaligned**
Steel	0.0050596	0.028948
Cast Iron	0.0095406	0.052745
Aluminium	0.018367	0.0811
Titanium	0.01242	0.059632

Table 8 Maximum Deformation for the Hypoid gear sets

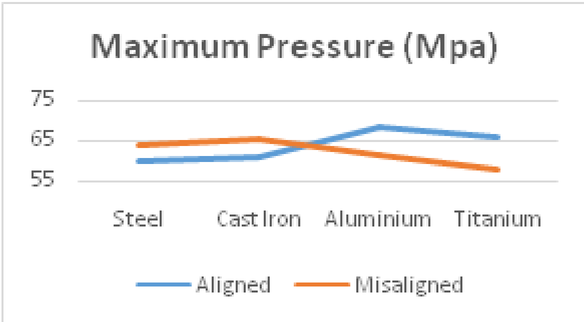


Graph3 Materials Used Vs Maximum Deformation

The above graph is drawn between the materials used for the hypoid gear sets Vs Maximum strain for the conditions of alignment and misalignment. From the above graph we can see that the increase in deformation during misalignment for the materials used is quite high and it is highest for aluminium and lowest for steel

Material Used	Maximum Pressure (Mpa)	
	Aligned	**Misaligned**
Steel	59.918	63.957
Cast Iron	60.834	65.334
Aluminium	68.355	61.272
Titanium	65.729	57.772

Table 9 maximum pressures of the hypoid gear sets



Graph 4 Material used Vs Maximum Pressure

From the above graph we can see the variations of pressures of aligned and misaligned hypoid gear sets we can see that there is a increase in pressure during misalignment for the Materials Steel and Cast Iron while there is a decrease in pressure for Aluminium and Titanium.

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CONCLUSION

In this thesis, the impact of misalignments on root stresses of hypoid gears is investigated. 3D modelling is done in CATIA V5. Two models with perfect alignment and misalignment are designed. The forces acting on the hypoid gear are calculated theoretically. Structural analysis and Modal analysis are done on the designed models to verify the stresses, strains, deformation and pressure developed.

The materials used are Steel, cast iron, Aluminium Alloy and Titanium. Analysis is done by ANSYS. By observing the analysis results, the stresses, strains, deformation and pressure of the hypoid gear are increased when the gears are misaligned. So it can be concluded the misalignment of contact defined as a major contributor of increasing of stress on the tooth root thereby probably could lead to a fatigue initiation at the maximum stress region and finally leads to breakage of the gear.

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