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Weight Optimization of Helical Gear Pair Using FEA on ANSYS

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Abstract—*In high speed power transmission between shafts gear plays a valuable role. In automotive gear box several types of gears were used for transmission in which helical gear pairs are over spur gears for effective transmission. In growing technology of automobile and aviation industries weight optimization of gears are in demand. Light weight gears can reduce the weight of the gear box and increase the efficiency of the engine. Weight can be optimized using changes in the design variable, design constaints, modification in design with matr=erial removal or change in material by using light weight alloy. The stress and deformation along with FOS is always taken into consideration beacuse reduction in weight will decrese the above factors but a allowable range of limit is permissible, so the optimized design should be in that limit.*

In this paper helical gear pair is taken into consideration with AGMA standards with design variables such as module, face width, number of teeth on pinion and helix angle. Design constraints considered are bending stress, compressive stress, module, gear ratio and centre distance. With the above data and formulation a helical gear pair is generated using Solid works designing software and it analysis will be done using ANSYS analysis software. These results were used for data validation and a improved helical gear pair design with lighter weight gear is also created on Solid works and weight optimization analysis is done on ANSYS. These two results were compared to check the percentage of weight optimization in helical gear pair.

Keywords*: Spur Gear, Weight optimization, Finite Element Analysis, FEA, FEM, Solid works, ANSYS, Gear Analysis.*

Introduction-

Gears are the most valuable mechanical element for the power transmission between two two shafts, either parallel or perpendicular. In automotive gear box, aviation aircrafts and heavy machineries there is a need of optimized gears with lower weight and volume withstand to the transmission requirement. Lower weight optimized gears can reduce the material requirement and cost of the gear and can increase the efficiency of the process.

In Constant mesh gear box of automotive vehicles helical gears are used beacaue helical gears have some benefits over spur gear like less noiser transmission during operation, gradual engagement of gear tooth reduces force applied on tooth surface, more efficient engagement increases the speed of transmission and increases the efficiency of transmission.

In this paper a helical gear pair is used according to AGMA gear standards for manufacturing of helical gear, these magnitudes, dimensions and mathematical equations are used for modelling of helical gear on Solid Works modelling software and this gear pair assembly is imported on ANSYS software for analysis. After analysis of the design values of total deformation, stress, strain and FOS were calculated. A improved geometry is introduced and a optimized weight is obtained by changing the geometrical design and removing material from the gear periphery.

Research Methodology:

A function is defined as the quantity to br minimized or maximized by analysing a search space under the imposed constraints. In this work , function considering is weight and volume for helical gear,

Minimize function[x] $= \frac{5X\pi Xm^2Xb}{4\,cos^2\,\beta}(Z_1^{\,2})$

Where,

m= Normal Module in mm

b= Face width in mm

$Z_{1=}$ No. of teeth on pinion

B = Helix Angle

F[x]= f[m,b,$Z_{1,}$β]= $\frac{5X\pi Xm^2b}{4\,cos^2\,\beta}(Z_1^{\,2})$

Design Variables:

The variables used in optimizing of helical gear pair are

Sr. No.	Design Variables	Limits
1.	Normal Module	2.5
2.	Face width	20
3.	No. of teeth on pinion	20
4.	Helix Angle	15°

Constraints Considered:

Sr. No.	Constraints	Equation
1.	Bending Stress	$\sigma_b = 0.7 \frac{(i+1)}{(a\, m_n b\, y_v)} \times [M_t]$ $\sigma_b \le [\sigma_b]_{al}$ $[Mt] = M_t \times k \times k_d$
2.	Compressive Stress	$\sigma_c = 0.7 \left(\frac{i+1}{a}\right) \times \sqrt{\frac{i+1}{ib} \times E \times [M_t]}$ $\sigma_c \le [\sigma_c]_{al}$
3.	Normal Module	$m_{min} = 1.15\, cos\beta \times \sqrt[3]{\frac{[M_t]}{(y_v[\sigma_b]\Psi_m Z_1)}}$ $m_n \ge m_{min}$
4.	Gear Ratio	$i = \frac{Z_2}{Z_1} = 2$
5.	Centre Distance Between Pinion and Gear	$a \ge a_{min}$ $a = \frac{m_n}{2cos\beta}[Z_1 + Z_2]$ $a_{min} = (i+1) \times \sqrt[3]{\left(\frac{0.7}{[\sigma_c]}\right)^2 \times \left(\frac{E[M_t]}{i\Psi}\right)}$ $\Psi = \frac{b}{a}$

Table. Manufacturing data for normal helical gear pair

Parameters	Module	Face Width	No Of teeth	Helix Angle	Outer Dia meter	Material
Gear	2.5	20	40	15	108.5	C.I
Pinion	2.5	20	20	15	56.7	C.I

Table. Manufacturing data for optimized helical gear pair

Parameters	Module	Face Width	No. Of teeth	Helix Angle	Outer Diameter	Material
Gear	2.5	20	40	15	108.5	C.I
Pinion	2.5	20	20	15	56.7	C.I

Case 1. Design Modelling in solidworks

Analysis of the Helical Gear Pair on ANSYS

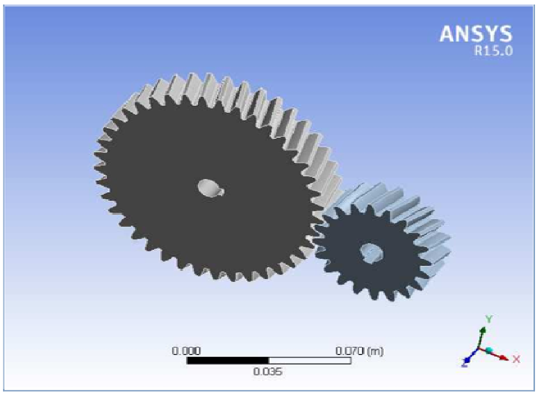

Figure 1. Helical Gear PairModel

Table 1. Mathematical Values

Properties	
Volume	2.0557e-004 m³
Mass	1.6137 kg
Statistics	
Bodies	2
Active Bodies	2
Nodes	55466
Elements	10516
Mesh Metric	None

Material		
Assignment	Structural Steel	
Nonlinear Effects	Yes	
Thermal Strain Effects	Yes	
Bounding Box		
Length X	0.12197 m	6.2288e-002 m
Length Y	0.12197 m	6.2288e-002 m
Length Z	2.e-002 m	
Properties		
Volume	1.657e-004 m³	3.987e-005 m³
Mass	1.3007 kg	0.31299 kg
Centroid X	-4.1865e-002 m	3.6643e-002 m
Centroid Y	-7.3315e-007 m	2.2858e-005 m
Centroid Z	9.9998e-003 m	1.0002e-002 m
Moment of Inertia Ip1	1.7574e-003 kg·m²	1.1059e-004 kg·m²
Moment of Inertia Ip2	9.2202e-004 kg·m²	6.5725e-005 kg·m²
Moment of Inertia Ip3	9.2198e-004 kg·m²	6.5684e-005 kg·m²
Statistics		
Nodes	36378	19088
Elements	6855	3661
Mesh Metric	None	

Meshing Generation

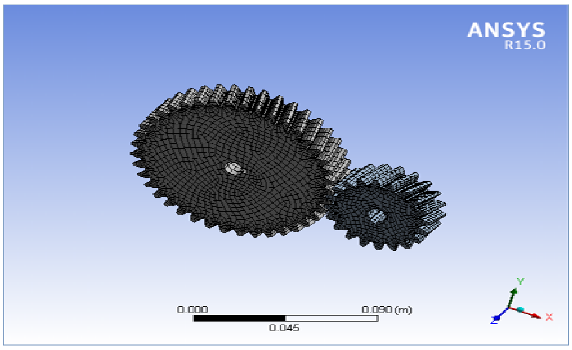

Figure 2. Meshing of Helical Gear OPair

TABLE 2. Static Structural Loads

Object Name	Frictionless Support	Moment
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	2 Faces	1 Face
Definition		
Type	Frictionless Support	Moment
Suppressed	No	
Define By		Vector
Magnitude		50. N·m (ramped)
Direction		Defined
Behavior		Deformable

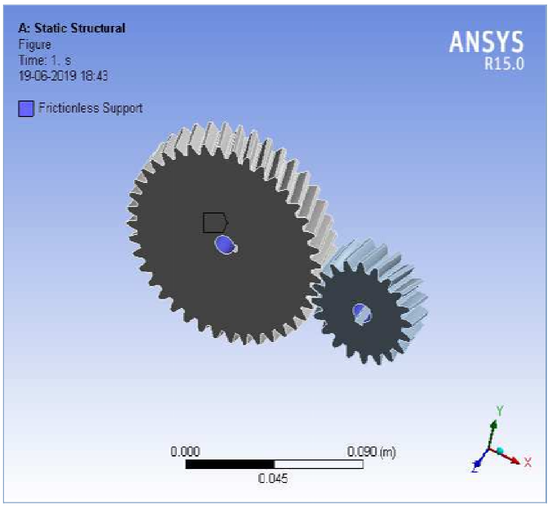

Figure 3. Frictionless Support

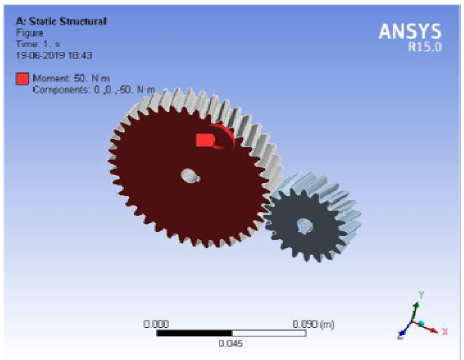

Figure 4. Moment

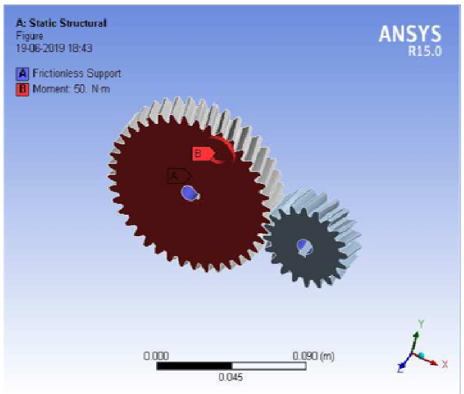

Figure 5. Static Structural

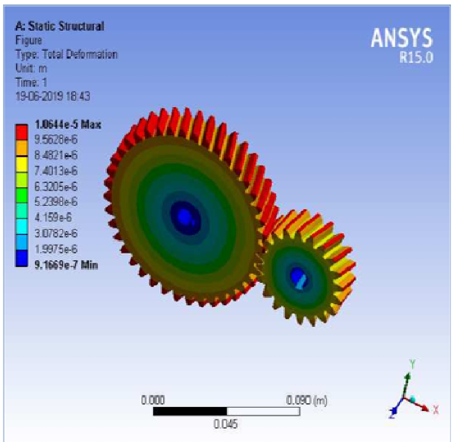

Figure 6. Total Deformation

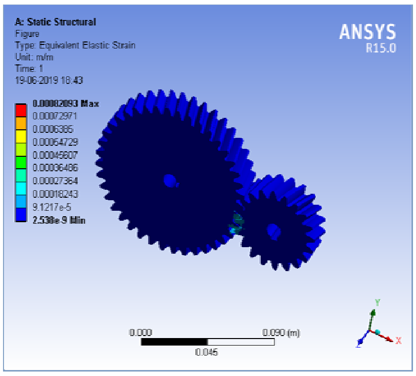

Figure 7. Equivalent Elastic Strain

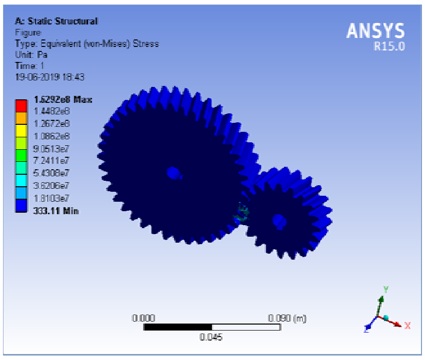

Figure 8. Equivalent Stress

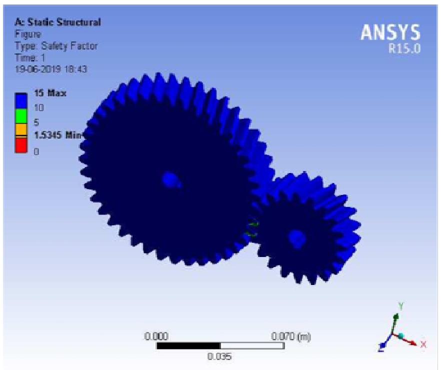

Figure 9.Safety Factor

Material Data

TABLE 17 Cast Iron

Density	7850 kg m^-3
3Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	434 J kg^-1 C^-1
1Thermal Conductivity	60.5 W m^-1 C^-1
Resistivity	1.7e-007 ohm

Case 2- A modified Design of helical gear pair with removal of material in the gear periphery is modeled on solid works software.

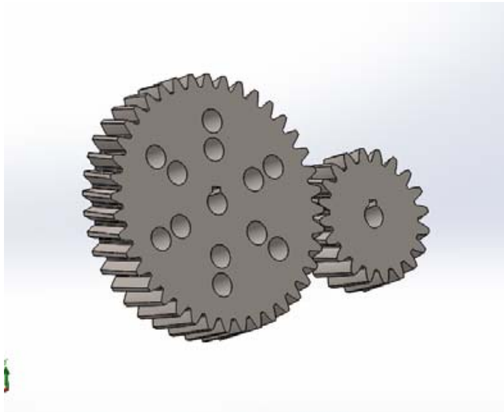

Figure 10. Solid Works Model

This geometric model of helical gear pair is imported to ANSYS analysis software and following analysis is calculated:

Sr. No.	Design Variables	Limits
1.	Normal Module	2.5
2.	Face width	20
3.	No. of teeth on pinion	20
4.	No. of teeth on gear	40
5.	Helix Angle	15°
6.	Helical Gear	Right Hand
7.	Pinion	Left Hand

Scoping Method Geometry Selection

Contact 4 Faces

Target 4 Faces

Contact Bodies helical gear_ Right Hand

Target Bodies helical gear_Left Hand

Meshing Generation

Sizing

Relevance Center Medium

Element Size Geometry

Initial Size Seed Active Assembly

Smoothing Medium

Transition Fast

Span Angle Center Coarse

Minimum Edge Length 7.9731e-004 m

StatisticsNodes 55466

Elements 10516

Mesh Metric No

a.Total Deformation

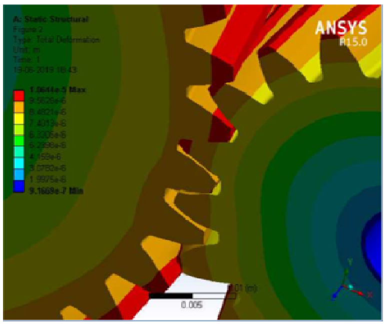

Figure Total Deformation

Total Deformation	
Minimum	9.1669e-007 m
Maximum	1.0644e-005 m

b. Equivalent Elastic Strain

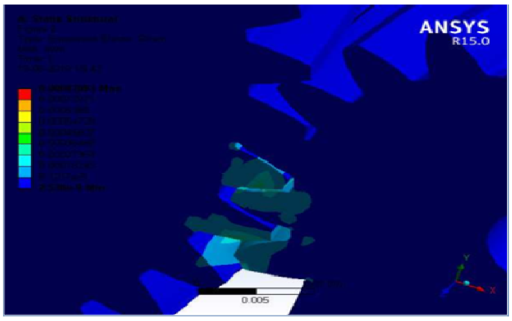

Figure. Equivalent Elastic Strain

Equivalent Elastic Strain	
Minimum	2.538e-009 m/m
Maximum	8.2093e-004 m/m

c. Equivalent Stress

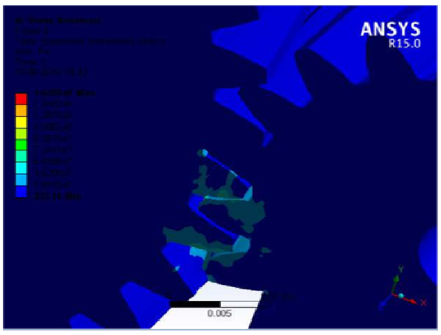

Figure Equivalent Stress

Equivalent (von-Mises) Stress	
Minimum	333.11 Pa
Maximum	1.6292e+008 Pa

d. Safety Factor

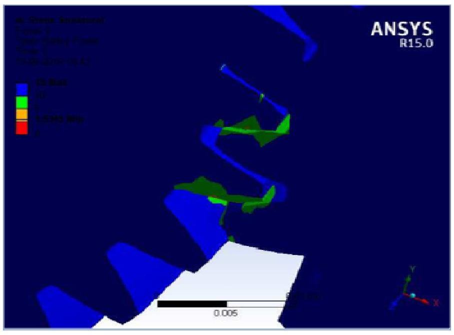

Figure Safety Factor

Results

Properties of Second Gear Pair Geometry	
Volume	0.000342922 m³
Mass	1.305 kg
Density	7850 kg/m^3
Weight	25.87 N

Volume	2.0557e-004 m³
Mass	1.6137 kg

So the results for case 1 and case 2 are compared

Weight = $W_1 - W_2$ = (1.6137 – 1.3050) Kg = 0.2887 Kg

Conclusion:

Weight optimization of helical gear pair is done with the necessary manufacturing data of helical gear pair has a taken according to AGMA, optimized value of weight is considered with the proper formulation of gear and all the design variables and constraints. A slight modification in the design with material removal on the periphery has given a optimized weight with slight changes in the stress, strain and deformation but these value are under the permissible range of working. So the analysis and improved modeling is valid.

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