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Finite Element Analysis of Helical Gear Pair for Bending and Contact Stresses

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Abstract: In gear design, excessive tooth contact stresses and bending stresses are one of the prime gear failure factors; therefore, its analysis is critical to shortening the possibility of gear tooth failure. In the present work, the tooth bending stresses and contact stresses in a helical gear pair is calculated using AGMA theory and finite element analysis (FEA). The modelling of the helical gear pair is carried out in CREO and ANSYS is used for FEA. It is observed that the bending stresses and contact stresses, both decreases with an increase in the helix angle if pressure angle remains constant. However, the error in the calculation by AGMA and FEA is higher for the bending stresses than the contact stresses and bending stresses.

Key words: Helical gear pair, bending stresses, Contact stresses

1. Introduction

Gears are utilized in the car, marine vessel, industrial gear, and many others. To transmit energy and movement between the shafts by using successively engaging teeth (Rattan, 2015). Generally, the gear failure is caused because of the excessive bending stresses or contact stresses generated in the course of the power transmission. Helical gears, in which tooth are cut at the particular angle (helix angle), are desired at high speeds because of the easy operation and decreased noise at some stage in the power transmission. Gears transmit movement, without connector or intermediate link, via direct contact. The tangential connection is made among the surfaces of mating gears, which have either rolling/sliding motion along the factor of contact (Rattan, 2015). When two bodies, having curved surfaces, are pressed together, the tangential contact changes the contact area resulting into the development of three-dimensional stresses. This phenomenon reasons for surface material failure within the form of pits, cracks or flaking.

The contact stresses develop when each meshing frame has a double radius of curvature, i.e. when radius in a perpendicular plane is different radius within the plane of rolling (Bhandari, 2013). Due to the pitting phenomenon, the gear tooth failure happens while the contact stresses between meshing teeth exceed the material's surface strength (Budynas & Nisbett, 2011). Several authors have investigated analytically/numerically the contact stresses in helical and spur tools pairs. The design of gear depends upon at the material properties and geometry of gear profile because they fulfil, suggest and indicate the useful necessities. Few authors have used composite materials as a way to attain longer gear existence, fewer teeth failure, less weight (Ganeshan & Vijayarangan, 1993; Pawar & Utpat, 2014; Venkatesh & Murthy, 2014). The gear layout criteria need to maximise the suitable effect, e.g., the existence of gear, capacity reliability and reduce unwanted impact, e.g., backlash. The goal of contemporary paintings is to analyse the outcomes of helix angle at the bending stresses and get in contact with emphasises in helical gear pair based on the AGMA (American Gear Manufacturing Association) principle and Finite Element Analysis (FEA). The CREO software program is used for the modelling of helical tools pair and bending, and contact stresses are calculated in ANSYS for predicting the gear teeth failure

2. Bending Stresses

Tooth bending stresses are an essential parameter for the design of gear pair. Several authors used either Lewis equation or AGMA theory for estimating the bending stresses in a gear pair. The maximum bending stresses are observed at the root of the gear tooth. AGMA theory defines the bending stresses by the following relationship

$$\sigma_b = \frac{F_t}{bmj} K_o K_v (0.93 K_m)$$

Where F_t the tangential load, m the module, j the geometry factor for bending stress and b the face width. Table 1 shows the magnitude of bending pressures based on the AGMA theory.

Table 1: Bending stresses based on AGMA

Helix Angle	Geometry Factor	Bending Stress (MPa)
15˚	0.4987	111.72
20 ˚	0.5005	111.32
25 ˚	0.5031	110.74
30 ˚	0.5066	109.97
Pressure angle = 20˚		

3. Tooth Contact Stresses

The tooth contact stresses is another criterion for the safe design of helical gear pair. The reduction in contact stresses reduces the level of noise during operation. Several authors have used 2D model for the contact stresses analysis of helical gear pair based on the analytical equation or FEA. Table 2 shows a summary of contact stresses analysis of helical gear pair carried out by the different authors.

Analytical Method

The analytical methods are used for estimating the bending stresses, tooth contact stresses and surface fatigue. Mostly, Hertzian and AGMA theories are used for calculating the contact stresses. The Hertzian approach is limited to the calculation of contact stresses for the frictionless surface having smaller contact area; therefore, AGMA theory is generally preferred.

AGMA Theory

AGMA theory defines the contact stresses as (Budynas & Nisbett, 2011)

$$\sigma_c = C_p \sqrt{\frac{F_t}{b d_p I}\left(\frac{\cos\Psi}{0.95 C_R}\right) K_o K_v (0.93 K_m)} \tag{1}$$

Where $_p$ the pitch circle diameter of pinion.

The elastic coefficient factor (C_p), geometry factor (I), contact ratio (C_R) may be expressed as (Budynas & Nisbett, 2011)

$$C_p = \sqrt{\frac{1}{\pi\left(\frac{1-v^2}{E_p}+\frac{1-v^2}{E_G}\right)}} \tag{2}$$

$$I = \frac{\sin\varphi\cos\varphi}{2}\frac{i}{i+1} \tag{3}$$

$$C_R = \left(\frac{\sqrt{(r_1+a)^2 - {r_{b_1}}^2} + \sqrt{(r_2+a)^2 - {r_{b_2}}^2} - (r_1+r_2)\sin\varphi}{\pi m \cos\varphi}\right) \tag{4}$$

S Jyothirmai et al. (Jyothirmaia et al., 2014) used AGMA concept for estimating the contact stresses and fatigue stresses to investigate the overall performance of gear pair regarding tooth energy, stresses generated at low speeds. Seok-Chul Hwang et al. (Hwang et al., 2013) used AGMA theory for calculating the contact stresses at the lower point and higher factor of teeth in contact. Other authors have used this concept for the contact stresses analysis of helical gear pair (Hwang et al., 2013; Patila et al., 2014; S.Sai Anusha, 2014; Khosroshahi & Fattahi, 2017; Devraj, 2015). The contact stresses, primarily based on Hertz and AGMA equations, decreases with a growth inside the helix angle, assuming the negligible coefficient of friction (Patila et al., 2014). B. Venkatesh et al. (Venkatesh et al., 2014) used AGMA idea for the structural analysis of helical gear and found a small difference with FEA. They concluded that appropriate material might also reduce the weight of gear pair.

Table 3: Contact stresses based on AGMA

Helix Angle	Pinion diameter (mm)	Gear diameter (mm)	Geometry factor	Contact ratio	Contact Stresses (MPa)
15˚	74.54	298.15	0.099	1.9015	664.42
20 ˚	76.62	306.48	0.1023	1.8316	650.81
25 ˚	79.44	317.77	0.1055	1.7428	633.61
30 ˚	83.14	332.55	0.1097	1.6360	613.04
For 14.5˚ pressure angle					

Table 4: Contact stresses based on AGMA

Helix Angle	Pinion diameter (mm)	Gear diameter (mm)	Geometry factor	Contact ratio	Contact Stresses (MPa)
15˚	74.54	298.15	0.1320	1.5919	631.86
20 ˚	76.62	306.48	0.1347	1.5317	620.26
25 ˚	79.44	317.77	0.1383	1.4558	605.56
30 ˚	83.14	332.55	0.1429	1.3655	587.89
For 20˚ pressure angle					

Finite Element Analysis

Modelling

3-D models are effective for designing and improving the accuracy in gear layout. The 3D version geometries are correct and enable us to test and evaluate the gear operation (Achar, et al., 2014; Htet San et al., 2017; Hedlund & Lethovaara, 2007). Ivana Atanasovka et al. (Atanasovaska et al., 2009) done FEA to determine the placement of contact line in the course of the contact duration. CH Rama and Mohana Rao (Mohana Rao & Muthuveerappan, 1993) identify the helical tools root stresses in a more practical way. Litvin et al. (Litvin et al., 2003) used 3-d version for double circular arc helical gear for determining the position blunders resulting from the gear surface mismatch. The layout criterion maximizes the applicable impact along with existence of tools, capability reliability and minimizes the undesirable effect (backlash). The helical gear pair is modelled in CREO software. Table 4 suggests the modelling parameters for the helical gear pair.

Table 4: Modelling parameters for helical gear

Gear Parameters	Value
Number of teeth on the gear	72
Number of teeth on a pinion	18
Gear diameter	332.64mm
Pinion diameter	83.2 mm
Pressure angle	20˚
Module	4
Face width	30.16 mm
Helix angle	30˚
Poisson ratio	0.3
Addendum	$1m_n$
Dedendum	$1.25m_n$

FE Analysis

FEA is used for solving complex engineering problem when the shape or implemented load is complex. Several authors have used (Pawara & Utpat, 2015; Kathona, 1994; Barbieri et al., 2014; Ganeshan & Vijayarangan, 1993; Wanga et al., 2015) FE stress evaluation for gear pair. Shalini Keshari et al. (Keshari & Srivastava, 2017) used FEA for optimization of the gear weight based entirely on genetic algorithms (GA) and particle Swarna optimization approach. In the existing work, the meshes are generated by use of triangular element (22362) with element length of 1mm to 10 mm. Fig. 1 shows the mesh generated within the helical gear pair. Fig. 2 indicates the boundary situations used in FEA in which helical gear is assumed to provide fixed assist whereas frictionless assist and moment load is applied on the mating gear (pinion). The magnitude of contact stresses is calculated by way of assuming helical gear of annealed AISI 8620 alloy steel with a tensile energy 530MPa and AISI 9310 alloy metallic with a tensile power 910MPa for the pinion. Poisson's ratio of 0.3 is considered.

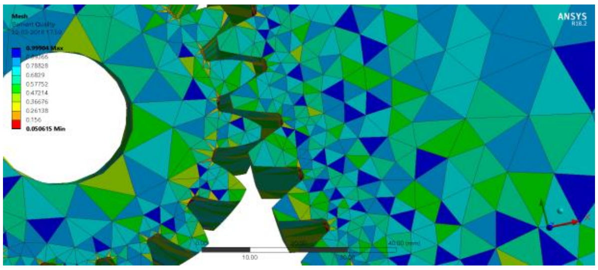

Fig 1: Mesh Element

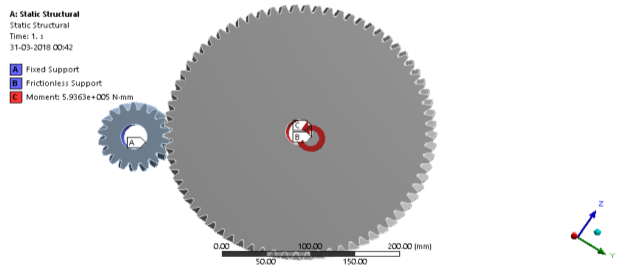

Fig 2: Boundary conditions in the helical gear pair

4. Results And Discussion

The bending stresses and contact stresses are calculated for specific values of helix angles (15˚, 20˚, 25˚and 30˚) with particular pressure angle (14.5˚, 20˚). Fig. 3 shows the validation of bending stresses at different helix angles, keeping the pressure angle constant at 20. It can be located that the bending stresses decrease gradually with an increase in helix angle. The errors in bending stresses between AGMA and FEA is maximum (16.4%) for 15˚ helix angle; but, it's far minimum (14.3%) for 30˚ helix angles. Fig. 4 indicates the variation of contact stresses at different helix angles, preserving the pressure angle fixed at 14.5. The contact stresses also decrease with an increase in the helix angle however the error among AGMA and FEA could be minimal (1.2%) for 25˚ helix perspectives. Fig. 5 shows the version of contact stresses at specific helix angles, maintaining the pressure angle fixed at 20. The contact stresses also decrease with an increase in the helix angle however the errors among AGMA and FEA could be minimal (0.74%) for 25˚ helix angles.

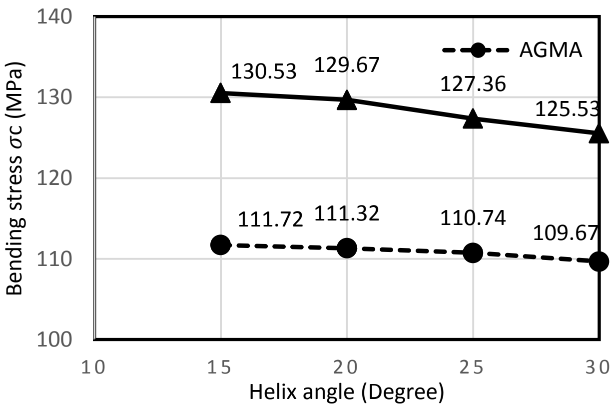

Fig. 3: Effect of helix angle on bending stresses

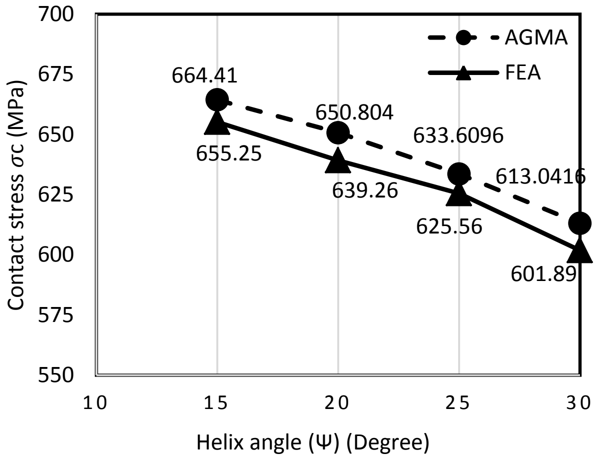

Fig. 4: Effect of helix angle on contact stresses for 14.5° pressure angle

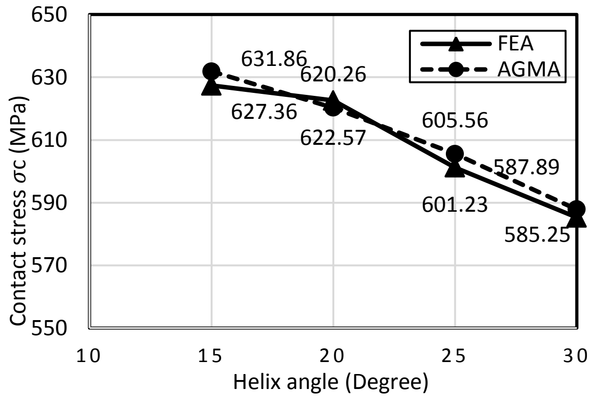

Fig. 5: Effect of helix angle on contact stresses for 20° pressure angle

5. Conclusion

Both bending stresses and contact stresses in helical gear pair depends on the helix angle, material and face width of gear. In the present work, the bending stresses and contact stresses are calculated using AGMA theory and FEA. Both stresses decreases with an increase in the helix angle. It is concluded that the error in the estimation of contact stresses using AGMA theory and FEA is approximately 0.7% for the pressure angle at 20^o and approximately 1.3% for the pressure angle at the 14.5^o error in the estimation of bending stresses is 16.4% for pressure angle at 20^o.

NOMENCLATURE

b_0	Contact area
l	Geometry factor
F	Component of force
K_B	Rim thickness factor
K_A	Application factor
K_l	Load factor
C_f	Surface condition factor
K_r	Reliability factor
K_T	Temperature factor
K_v	Dynamic factor
K_s	Surface factor
C_p	Elastic coefficient
K_m	Load distribution factor
K_o	Overload factor
P_a	Axial pitch
d_p	Pinion pitch diameter
Ψ	Helix Angle
m_n	Normal Module
ϕ	Pressure Angle
J	Factor for Geometry
K_s	Size factor
P_d	Diametral pitch
E	Elastic module
W^t	Tangential tooth load
v	Poisson ratio

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