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Contact and Bending Stress Analysis of Gears- A Review

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Abstract*: Gear is a mechanical element used to transmit power between to shafts. Due to repetitive cyclic loading, gear tooth is subjected to contact and bending stress. Contact stress developed at the contact point of two mating gears and bending stress occurs at the root fillet of the gear tooth. Tooth surface failure happens when the contact stress exceeds fatigue strength of the gear material. Tooth breakage at the root fillet occurs when the bending stress exceeds bending strength of the gear tooth. This paper gives an overview of gear tooth failure due to cyclic loading at contact point and root fillet. Many authors have tried different approaches to analyse the gear tooth failure such as FEM, AGMA standard and analytical method. Contact and bending stress can be calculated analytically by Hertz and Lewis bending equation respectively.
Keywords: Fatigue load, Tooth failure, Contact stress, Bending stress, FEM, AGMA

I. INTRODUCTION

In industries, many types of transmission systems are used to transmit mechanical power from source to destination such as belt drives, wire ropes, chains and gears etc. Among all the transmission systems, gear drives are widely used because of its high efficiency. Since it is a positive drive, gears are used in the range from smaller toys to larger ships. As the necessity increases, different gear materials, gear profiles are to be used to fulfil the needs. Power transmission takes place due to meshing action between two mating gears. Gear tooth failure occurs at mating point and root fillet as a result of repeated cyclic load. Excessive contact stress at contact point causes surface failure and bending stress developed at root fillet causes tooth breakage.

Hence it becomes a thrust area for researchers to design a gear based on tooth stress to transmit more power with optimized weight and improved strength. The research is going on over a longer period but still there is a scope for researchers to realize the various factors which affects this stress. Fig 1 shows the development of contact stress at mating point and bending stress at root fillet of the spur gear.

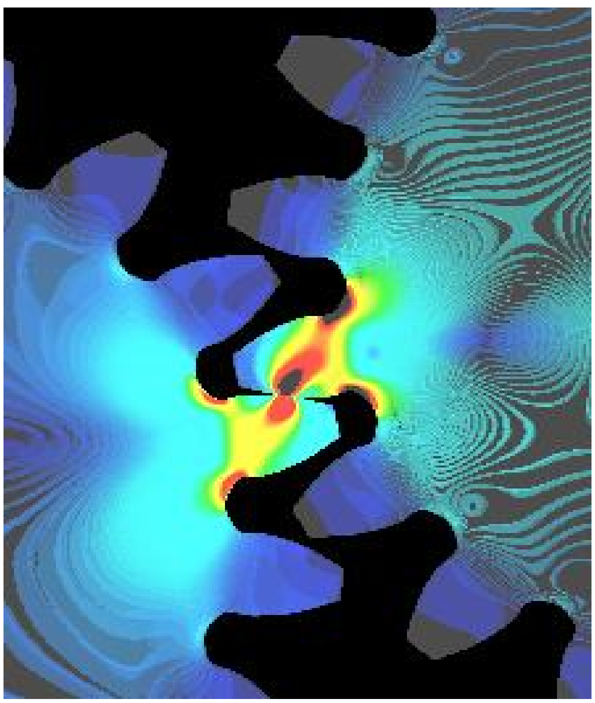


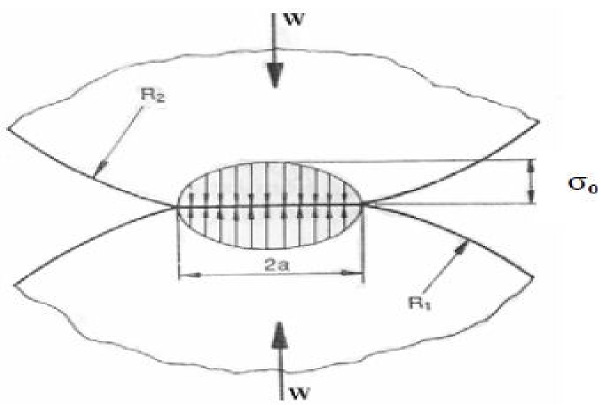
Fig. 1 Contact and Bending stress

II. LITERATURE REVIEW

A detailed study is carried out to expose the recent developments in stress analysis of various gears.

Seok-Chul Hwang et al [1], had done the work on contact stress analysis for a pair of mating gears during rotation. Contact stress analysis is carried out on spur and helical gears during rotation at different contact points. The variation of the contact stress is compared at the lowest point of single-tooth contact with AGMA equation.

JongBoon Ooi, et al [2] have done research on modal and stress analysis of gear box used in portal axle. Contact and bending stress analysis is carried out on three different gear configurations with varying angular positions from 0 to 18 degrees. The bending stress at the gear root fillet and the contact stress on the gear surface of the input and output gears are documented with every 2 degree of angular incremental. Contact stress was calculated analytically by Hertz equation. It is based on the analysis of two cylinders under radial load with an assumption of radius of the cylinder is equal to radius of pitch circle.



$$\sigma_0 = \sqrt{\frac{W\left(1+\frac{r_{b1}}{r_{b2}}\right)}{r_{b1} b_w \pi \left[\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right]\sin\phi}}.$$

Fig 2. Hertz contact stress model under radial load [2]

Analytical bending stress was calculated using Lewis equation with the consideration of few assumptions.

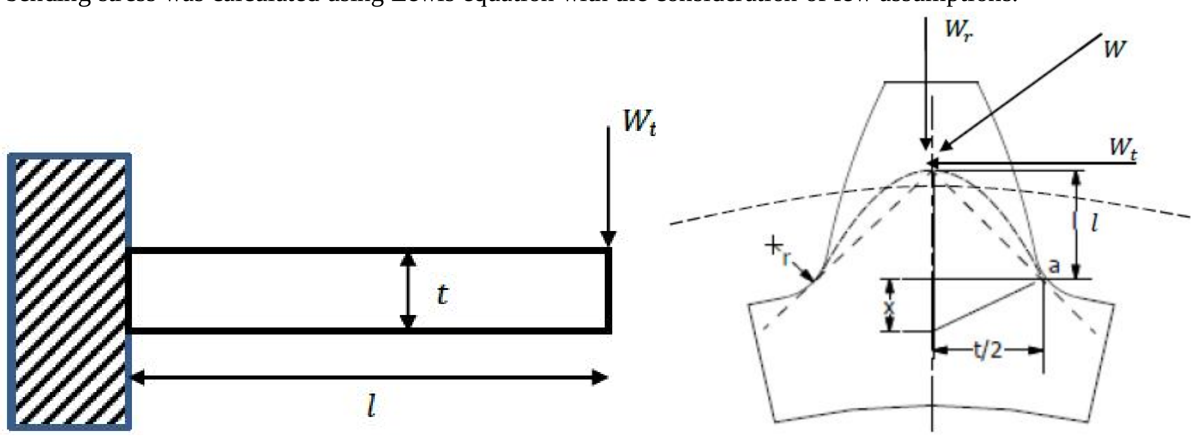


Fig 3. Lewis bending stress model under tangential load [2]

Both contact and bending stresses were simulated in ANSYS workbench software with different boundary conditions. Finally all the theoretical stress results are validated with FEM result.

Newton K. Fukumasu, et al [3] have done research on stress analysis of helical gear to improve contact resistance. The research mainly focused on contact stress analysis of helical gear and its relation with gear material properties and residual stress. The proposed gear was subjected to carbo-nitriding surface treatment and categorized by X- ray diffraction, nano-intendation and Vickers micro-hardness. The properties are fetched in to FEM and assessment was carried out. Finally the author concluded that, the increase in the residual stresses causes the reduction of all sort of stresses at the contact point. It leads to improvement on pitting resistance at the surface of the tooth.

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Bharat Gupta, et al [4] describes the contact stress analysis of spur gear. The objective of this work is to calculate the contact stress by using Hertz theory and compare with FEM results. Spur gear was modeled through parametric modelling in Pro-E software.

Table 1. Input parameters [4]

S.No	Parameters	Value
1	Module	2 mm
2	Shaft angle	180 degree
3	Input power	2 KW
4	Speed ratio	1
5	Pinion speed	50 rpm
6	No of teeth	25
7	Pressure angle	20 degree
8	Pinion material	40 Cr 4
9	Gear material	45 C 8`

Hertz stress was calculated for various module values from 2mm to 9 mm. The modeled gear was imported to ANSYS workbench for stress analysis. Contact stress at mating point is simulated and the corresponding results are obtained for various module values.

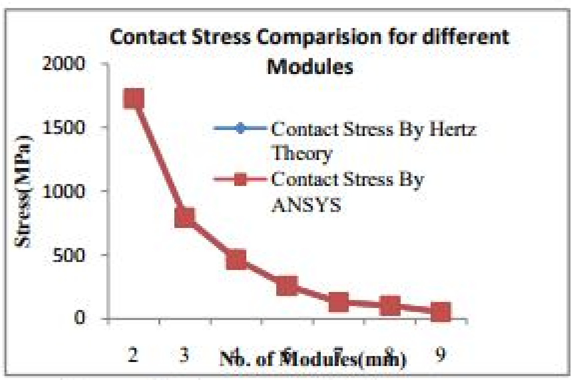

Fig 4. Contact stress comparison based on module [4]

It is concluded that, Surface failure can be prevented by increasing material hardness. From the Fig.4 it is revealed that the contact stress decreases with increasing module value.

Ali Raad Hassan [5] did a research work on Contact stress analysis between two spur gear teeth at different contact positions, during pure rotation of mating gears. A setup was established to ensure the pair of mating gears. During rotation for each and every location of contact the setup gives graphical results. FEM models were made and stress analysis was carried out.

Sarfraz Ali N. Quadri, et al [6] analysed the contact stress of involute spur gear. A pair of spur gear in a lathe has taken for analysis under static loading condition. Contact stress was calculated theoretically and compared with FEM results. The mating gears are modelled with 2 mm module in Creo 2.0 and then analysed in Ansys 14.5. Pinion is applied with fixed support whereas gear is applied with frictionless support as a boundary condition.

N. D. Narayankar, K. S. Mangrulkar [7] have worked on Contact Stress and Bending Stress Analysis of Spur Gear by Analytical Method. Finally the author concluded that the surface failure starts with the development of pits at mating point of gears leads to rupture of tooth. A pair of spur gears with 20° full depth have taken for analysis. Material for Pinion and gear is assigned as steel. Hertz contact stress is 169.22 N/mm^2 and Lewis bending stress is 200 N/mm^2. The gear is designed to withstand 15.4 kN load.

Ratnadeepsinh M. Jadeja, et al [8] studied on Bending Stress Analysis of Bevel Gears. Aim of this work is the estimation of bending stress developed at the root of tooth during the application of torque on straight bevel gear, spiral bevel gear and zero bevel gear. Bending stress was calculated numerically for straight bevel gear, spiral bevel gear and zero bevel gear derived from Lewis bending equation. Gears are modeled in PTC Creo. ANSYS workbench 14.0 is used to analyse the bending stress by FEM. For mesh, tetrahedron element type has chosen with 1 mm size at all faces and 0.5 mm at critical areas.

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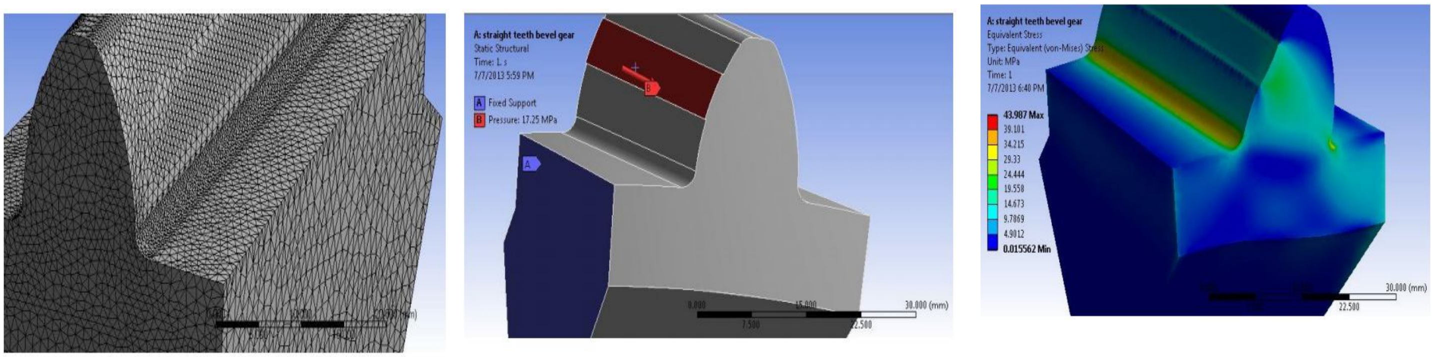

(a) (b) (c)

Fig 5. (a) Meshing (b) boundary condition (c) Bending stress [8]

Fixed support is taken as a boundary condition to obtain maximum bending stress for straight bevel. The same procedure was applied to other two gear types and results are obtained. From the analysis it is concluded that, straight bevel gear has higher strength to resist stress and it can take more load.

Amlan Das [9] carried out Finite Element Stress Analysis of Spiral Bevel Gear. Scope of this paper is to improve the transmission performance of the spiral bevel gear. Bending and surface stress of the tooth is prime causes for failure. It is mandatory to minimize the failure with an optimized design. Analytical calculations was done with AGMA equation and analysed in ANSYS 14.5. From the results it noted that increasing face width results decreasing contact and bending stresses. Tooth height plays a major role and it should not be modified unnecessarily. Shorted height should be avoided. AGMA and FEM results are compared and reveals that the FEM stress value is higher than AGMA.

S.Sai Anusha, et al [10] presented in their paper that focus on Contact Stress Analysis of Helical Gear by Using AGMA and ANSYS. Contact stress analysis is carried out on helical gear for different pressure angles, face width and helix angle. Gears are modeled in Peo-E software and analysed in ANSYS. An analytical approach is done based on Hertz equation.

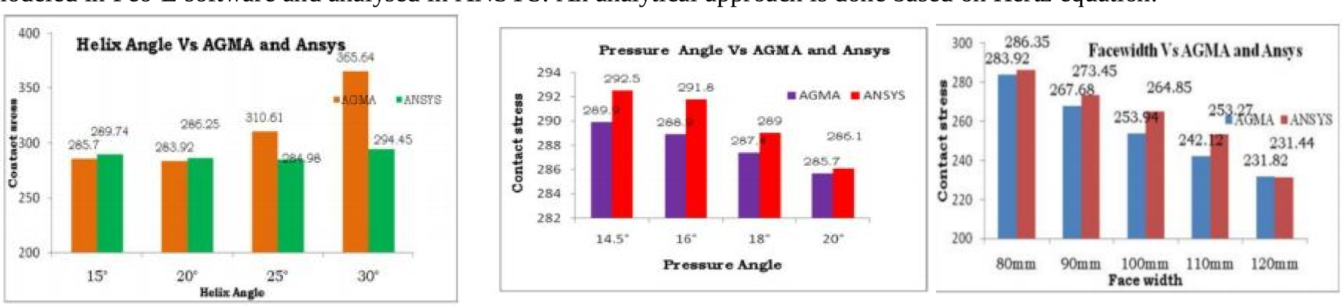

Fig 6. Variation of contact stress [10]

Fig 6. Shows the variation of contact stress with respect to helix angle, pressure angle and face width. From the observation, the stress value reduces with increasing face width.

S. K. Sureshkumar, S. Navaneethan [11] made an attempt on contact stress analysis of helical gear pairs of different helix angle. In this study, helical gear pairs are assigned with three different materials such as Steel, Cast Iron and Aluminium. Stress analysis is carried out by varying the helix angle. CATIA V5 is used to model the gears with different helix angle. Analysis is carried out in ANSYS.

Table 2. Contact stress for different helix angle [11]

Helix Angle (Degree)	Contact Stress (Steel) N/mm2	Contact Stress (CI) N/mm2	Contact Stress (Al) N/mm2
10	28.60	28.93	28.43
15	43.79	44.32	42.96
20	69.72	70.26	68.85
25	75.85	76.04	75.51

Table 2 shows that, increasing helix angle results increasing stress values. Among three materials, Aluminium is subjected to less stress.

Amit S. Shelake, N. S. Hanamapure [12] have discussed about Bending Stress Analysis of Worm Wheel of Winch Machine Gearbox Using 3D Photoelasticity and FE Analysis. This paper signifies the analysis of stresses using analytical, experimental and FE analysis. Theoritical part is carried out using Lewis bending equation. Experimental process was done with photoelasticity method.

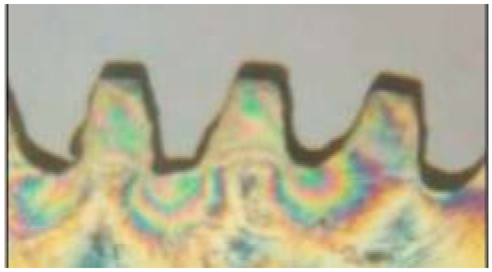

Fig 7. Photoelastic experiment [12]

Figure shows the observation of fringe pattern at the tooth root slices using polariscope. At root of marked tooth on the each slice, the isoclinic and isochromatic fringes were observed by using plane and circular Polariscope. All the values of fringe orders were noted down.

Table 3. Bending Stress [12]

Theoritical N/mm^2	Experimental N/mm^2	FE analysis N/mm^2
144.64	118.29	122.28

From table 3. it is clear that the design of worm wheel is safe as the ultimate tensile strength of wheel material PB2 is 320 N/mm^2.

III.CONCLUSIONS

From the literature, it is clear that bending and contact stresses are main factors which influences the gear performance and life. Surface life of the gear can be improved by subjecting the gear material with different surface treatment process. Gear parameters are also influences the performance greatly. FEM analyse can be done with various FEM packages.

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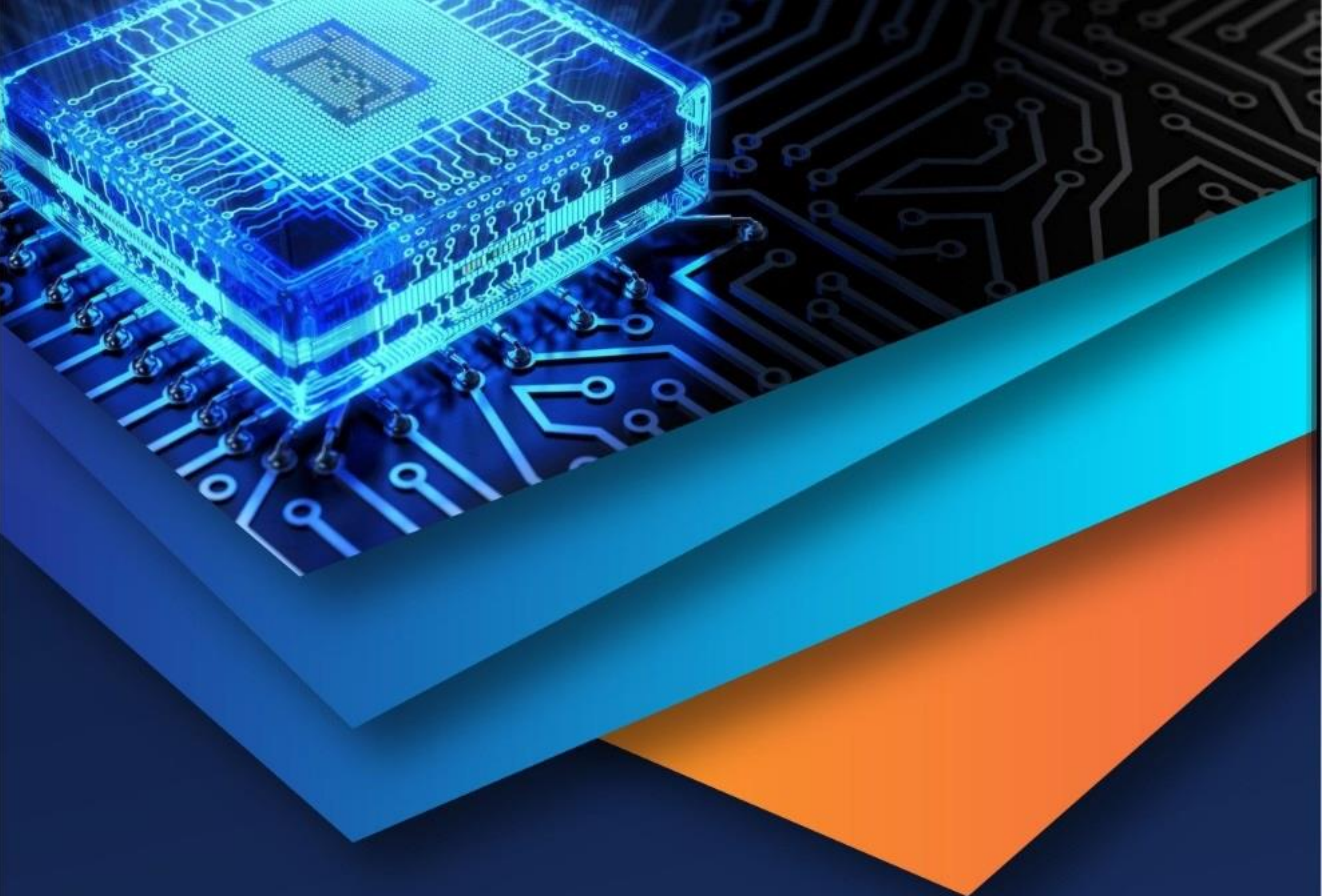

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