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EFFECT OF STRESS RELIEVING FEATURES ON STRESSES OF INVOLUTE SPUR GEAR UNDER STATIC LOADING

Sarfraz Ali N. Quadri
M.E. (CAD/CAM)
Department of Mechanical Engineering
MGM's Jawaharlala Nehru Engineering College, Aurangabad (M.S.), India
E-mail: sarfrazaliquadri@gmail.com

Dhananjay R. Dolas
Associate Professor
Department of Mechanical Engineering
MGM's Jawaharlal Nehru Engineering College, Aurangabad (M.S.), India
E-mail: dhananjay_dolas@rediffmail.com

ABSTRACT

This work made an attempt to summarize about stresses developed in a mating spur gear which has involute teeth. A pair of spur gears are taken from a lathe gear box and progressed onward to calculate stresses in their teeth. Conventionally the analysis is carried out analytically using Lewis formulae and then Finite Element Analysis is used for the same. In this study some stress reliving features have been incorporated in the teeth to know their effect on the stress concentrations. A finite element model of teeth is considered for analysis and geometrical features of various sizes are introduced at various locations and their effect is analyzed.

Keywords

Stress Analysis, Involute spur gear, static loading, Lewis formulae, Stress relieving features.

1. INTRODUCTION

Gears are used for a wide range of industrial applications. They have varied application starting from textile looms to aviation industries. They are the most common means of transmitting power. They change the rate of rotation of machinery shaft and also the axis of rotation. For high speed machinery, such as an automobile transmission, they are the optimal medium for low energy loss and high accuracy. Their function is to convert input provided by prime mover into an output with lower speed and corresponding higher torque. Toothed gears are used to transmit the power with high velocity ratio. During this phase, they encounter high stress at the point of contact. A pair of teeth in action is generally subjected to two types of cyclic stresses: Bending stresses inducing bending fatigue Contact stress causing contact fatigue. Both these types of stresses may not attain their maximum values at the same point of contact. [1]

However, combined action of both of them is the reason of failure of gear tooth leading to fracture at the root of a tooth under bending fatigue and surface failure, due to contact fatigue.

The surface failures occurring mainly due to contact fatigue are pitting and scoring. It is a phenomenon in which small particles are removed from the surface of the tooth due to the high contact stresses that are present between mating teeth. [9] Pitting is actually the fatigue failure of the tooth surface. Hardness is the primary property of the gear tooth that provides resistance to pitting. In other words, pitting is a surface fatigue failure due to many repetitions of high contact stress, which occurs on gear tooth surfaces when a pair of teeth is transmitting power. Gear teeth failure due to contact Fatigue is a common phenomenon observed. Even a slight reduction in the stress at root results in great increase in the fatigue life of a gear. For many years, gear design has been improved by using improved material, hardening surfaces with heat treatment and carburization, and shot penning to improve surface finish etc. This study gives an approach to determine the contact stresses and bending stresses which will help to improvise the performance of the gearing system.

2. LITERATURE REVIEW

Investigators analyzing the gear tooth for stresses have done several studies:

V. Rajaprabhakaran & et al. (2013) presented a study by adding different shaped holes to reduce stress concentration. A finite element model of Spur gear with a segment of three teeth is considered for analysis and stress concentration reducing holes of various sizes are introduced on gear teeth at various locations. Analysis revealed that aero-fin shaped hole introduced along the stress flow direction yielded better results.

A Manoj Hariharan (2006) conducted stress analysis on 8 different gears by determining the highest point of contact for all gears. Stress analysis for the load contact point travelling along the involute curve is done for gears. The point of contact where maximum stress occurs is determined for all eight test gears and the variation of this H (Highest point of Contact) diameter for contact ratio greater than one is studied. Then the gear ratio where it is maximum is taken for application of force for all studies. From the results, he compared the stresses on each gear with their respective highest point of contacts and selected the weak gear among those for stress relief studies. He introduced circular holes as stress relieving features at different locations and also varied the diameters of holes. He concluded with an optimization study of drilling two circular holes, each on two mating teeth at the same location relative to each tooth, stress can be reduced.

Shanmugasundaram Sankar et al., (2010) did a study using circular root fillet instead of the standard trochoidal root fillet. The result reveals that the circular root fillet design is particularly suitable for lesser number of teeth in pinion and where as the trochoidal root fillet gear is more opt for higher number of teeth. Ashwini Joshi and Vijay Kumar Karma (2010) did a work which deals with the effect on gear strength with variation of root fillet design using FEA. Circular root fillet design is considered for analysis. The loading is done at the highest point of single tooth contact (HPSTC).

Vishwas S. Jadhav(2007) discusses an experimental setup which will directly give stresses at varying load and speed conditions through a calibrated electronic strain gauge indicator, they generated a finite element model of spur gear and performed stress analysis while considering addition of no. of holes in the gear blank.

S. Tiwari (2012) & et al. uses a 3D model of gear and finite element analysis to conduct RBS and SCS calculation for mating involute spur gears. A pair of involute spur gear without tooth modification and transmission error is define in a CAD system (CATIA V5 and AUTODESK INVENTOR etc.) and FEA is done by using finite element software ANSYS. Obtained FEA results is comparable with theoretical and AGMA standard. V. Rajaprabhakaran & et al. presented a study by adding different shaped holes to reduce stress concentration. A finite element model of Spur gear with a segment of three teeth is considered for analysis and stress concentration reducing holes of various sizes are introduced on gear teeth at various locations. Analysis revealed that aero-fin shaped hole introduced along the stress flow direction yielded better results.

M. Raja & et al. (2014) work made an attempt to summarize about contact stresses developed in a mating spur gear which has involute teeth. A pair of spur gears are taken from a lathe gear box and proceeded forward to calculate contact stresses on their teeth. Contact failure in gears is currently predicted by comparing the calculated Hertz contact stress to experimentally determined allowable values for the given material. The method of calculating gear contact stress by Hertzian equation originally derived for contact between two cylinders. Analytically these contact stresses are calculated for different module, and these results are compared with the results obtained in modeling analysis in ANSYS.

Ali Raad Hassan (2009) did a research study in which Contact stress analysis between two spur gear teeth was considered in different contact positions, representing a pair of mating gears during rotation. A programme has been developed to plot a pair of teeth in contact. Each case was represented a sequence position of contact between these two teeth. The programme gives graphic results for the profiles of these teeth in each position and location of contact during rotation. Finite element models were made for these cases and stress analysis was done. The results were presented and finite element analysis results were compared with theoretical calculations, wherever available. The idea of using holes to reduce stresses is not a new one. In 1990, Dippery (Ali Raad Hassan, 2009) experimented with the use of supplementary holes in a structure as a method of reducing the stress concentration that was already present. His result showed that stress concentration reductions are possible in a generic shape using holes as stress relief. The researchers till now used circular and elliptical holes as stress relieving features with different sizes and at various positions which showed evidence that stress can be reduced interrupting the stress flow path from contact point to fillet.

3. STRESS ANALYSIS OF SPUR GEAR

3.1 Analytical Method of Stress Analysis

Wilfred Lewis in 1893 provides a formula for estimating the stresses in a tooth. He modeled a gear tooth taking the full load at its tip as simple cantilever beam. If we substitute a gear tooth for the rectangular beam, we can find the critical point in the root fillet of the gear by inscribing a parabola. In the Lewis Analysis some assumptions are to be considered which are as follows:

- The Gear tooth act as a cantilever beam.
- The Tangential component causes the bending moment about the base of the tooth.
- The effect of Radial components is neglected.
- The tangential component is uniformly distributed over the face width of tooth.
- The effect of stress concentration is neglected.

- It is assumed that at any time only one tooth will be in contact and takes the total load.

The weakest section of the gear tooth is at the section BC, where the parabola is tangent to the tooth profile.

At the section BC the moment will be,

$$M_b = P_t \times h$$

where,

$$P_t = m.b.\sigma_b Y$$

The bending stresses are given by,

$$\sigma_b = \frac{M_b.y}{I}$$

where,

$$I = \frac{b.h^3}{12}$$

Where,

M_b = Moment at BC

m = module of gear

P_t = Tangential Load

b = Face width

h = depth of tooth

I = moment of Inertia

Lewis has defined factor "Y", which is also known as Lewis form factor,

Table 1 Values for Lewis form factor for 20o full depth involute system

Number of Teeth	Lewis Form Factor "Y"
25	0.340
45	0.399
55	0.415
60	0.421
75	0.433
90	0.442
Rack	0.484

In this study Involute spur gear from the lathe machine gear box is considered which has following dimensions and material properties,

Table 2 Dimensions of the Spur gear

Dimension	Unit	Values
No. of teeth	-	54
PCD	Mm	108
Pressure Angle	Deg	20
Addendum radius	Mm	56
Dedendum radius	Mm	51.5
Module	Mm	2
Face Width	Mm	12

Table 3 Material Properties

Material Property	Unit	Grey Cast Iron
Density	Kg/m3	7200
Young's modulus	Pa	1.1E+11
Poisson's Ratio	-	0.28
Bulk Modulus	Pa	8.33E+10
Shear Modulus	Pa	4.29E+10

The Lathe machine gear box is powered by a 2.2 Kw motor which provides a Torque of 70028.17 N.m.

So,

$$P_t = \frac{Torque}{Radius} = \frac{70028.17}{54} = 1296.81N$$

$$M_b = 1296.81 \times 4.5 = 5835.68N/m^2$$

$$y = \frac{3.14}{2} = 1.577$$

$$I = \frac{12 \times 4.5^3}{12} = 91.125Kg/m^2$$

$$\sigma_b = 5835.68 \times \frac{1.577}{91.125} = 100.54 Mpa$$

3.2 Finite Element Method for Stress Analysis (ANSYS 14.5)

To estimate the stresses the Involute Spur gear tooth is modeled in CreO 2.0 modeling software. The model is then imported to the ANSYS 14.5 Mechanical modeler for stress analysis under static loading, the spur gear model is meshed with Tetrahedron Elements with different mesh sizes at different portion for more precise & accurate results. The fixed fixed support at the base and two frictionless supports at two slant faces of the geometry with force acting on the tooth of pinion which acts as cantilever. The boundary conditions and force application is also shown in the below.

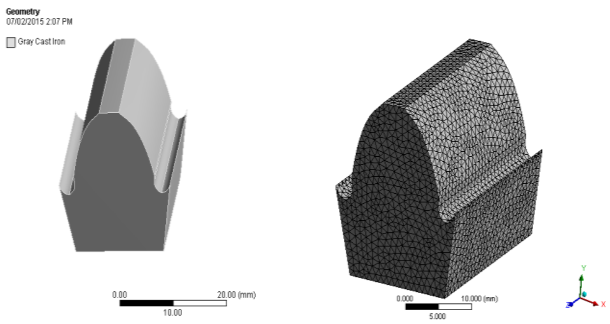

Figure 1 3D Model & Meshed Model of Spur Gear

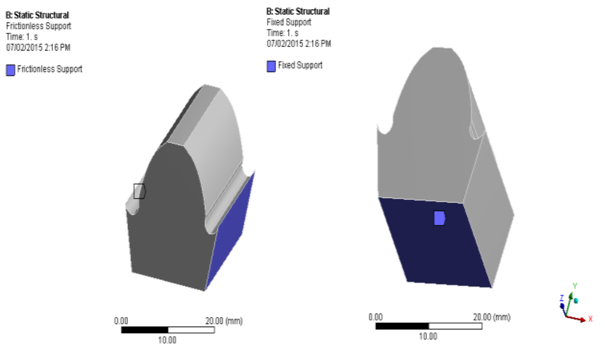

Figure 2 Fixed & Frictionless Supports

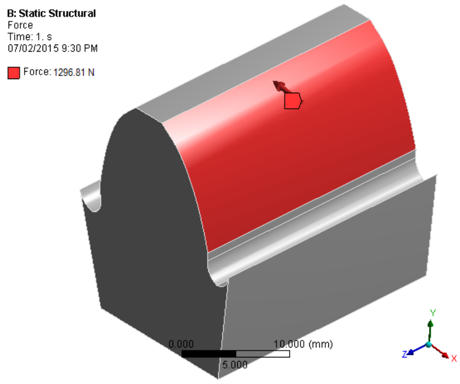

Figure 3 Force

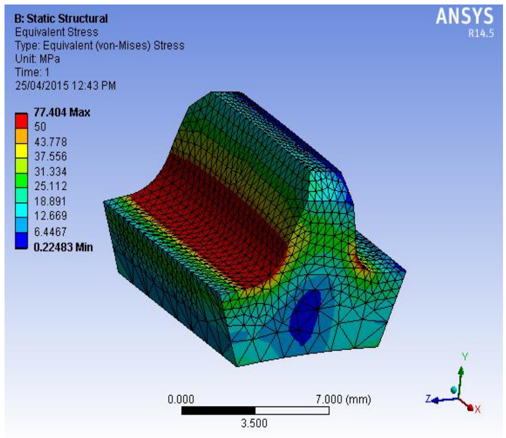

Figure 4 Equivalent stresses of Spur Gear

4. Results & Discussions

The stress reliving features are added at different five locations across the teeth geometry with varying sizes. The five locations are selected by considering the tooth as a cantilever so three locations are on the fixed support of the cantilever whereas two locations are across the hanging part of the cantilever. The results of the same are tabulated below in Table No 4.

Table 4 Results of stress relieving features of different Sizes at different Locations

Locations (x,y)	Diameters (mm)	Equivalent (von-mises) stresses (mpa)	Total Deformations (mm)
L1	1	90.512	0.00464
(50.74 , 4)	1.5	119.02	0.00519
L2	1	75.91	0.00458
(50.74,2.43)	1.5	75.66	0.00461
L3	1	80.09	0.00475
(50.74,0.86)	1.5	94.41	0.00500
L4	1	86.50	0.00492
(54 , 2.43)	1.5	109.03	0.00502
L5	1	91.142	0.00474
(52.5 ,2.43)	1.5	103.62	0.00496

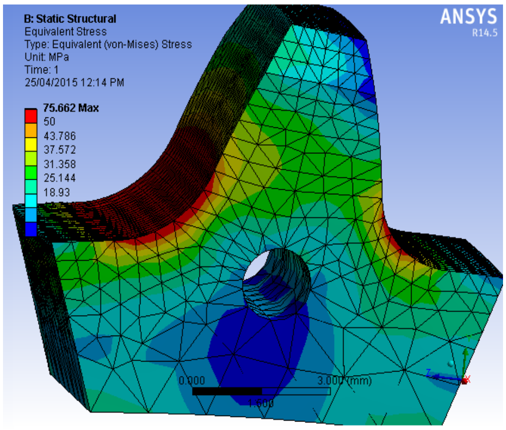

Figure 5 Equivalent stresses of Spur gear with stress relieving feature at location 2

5. Conclusion

This study mainly focuses on the concentration of stresses in a gear tooth. The stresses are calculated analytically using Lewis Formulae as well as using Finite element method. The results from both the methods have a slight percentage of difference, so we can consider FEM results for further study with ease. The effect of stress reliving features on the stresses is determined using finite element analysis; five locations are selected across the tooth geometry which is analyzed for two different sizes of the stress relieving feature. The best location of stress reliving feature and best size is find out after comparing stress analysis at all the pre-selected locations and sizes.

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6. REFERENCES

[1] V. Rajprabhakaran, R. Ashokraj, " Spur Gear Tooth Stress Analysis And Stress Reduction", IOSR Journal of Mechanical and Civil Engineering, PP 38-48, 2013.

[2] Ali Raad Hassan (2009), "Contact Stress Analysis of Spur Gear Teeth Pair", World Academy of Science, Engineering and Technology, Vol. 3, pp. 597-602.

[3] Ashwini Joshi and Vijay Kumar Karma (2010), "Effect on Strength of Involute Spur Gear by Changing the Fillet Radius Using FEA", International Journal of Scientific & Engineering Research, Vol. 2, No. 9.

[4] Hariharan_ME_Thesis (2006), "Spur Gear Tooth Stress Analysis and Stress Reduction Using Stress Reducing Geometrical Features", Thapar Institute of Engineering and Tech- nology, 2006. dspace.thapar.edu:8080/dspace/bitstream/123456789/.../8048113.pdf

[5] M. Raja, P. Phani, "Contact pressure analysis of spur gear using FEA", International Journal of Advanced Engineering Applications, Vol.7, Iss.3, pp.27-41 (2014).

[6] S. Shinde, A. Nikam " Static Analysis of Spur Gear Using Finite Element Analysis", IOSR Journal of Mechanical and Civil Engineering, PP: 26-31

[7] S. Tiwari, U. Joshi, "Stress Analysis of Mating Involute Spur Gear Teeth", International Journal of Engineering Research & Technology (IJERT) Vol. 1 Issue 9, November- 2012.

[8] Shanmugasundaram Sankar,Nataraj (2010), "Profile Modification for Increasing the Tooth Strength in Spur Gear Using CAD", Scientific Research.

[9] Sumit Agrwal, R.L. Himte,"Evalution of Bending Stress at Fillet Region of an Asymmetric Gear with a Hole as a stress relieving feature using a FEA Software ANSYS". International Journal Of Computer Application Volume 51-No 8, Aug 2012

[10] Sushil Kumar Tiwari, Upendra Kumar Joshi, Stress Analysis of moving involute spur gear teeth ISSN:2278-0181

[11] Vivek Karaveer, T. Mogrekar: " Modeling and Finite Element Analysis of Spur Gear", International Journal of Current Engineering and Technology, Vol3., No.5 (December 2013).