IPASJ International Journal of Mechanical Engineering (IIJME)
Web Site: http://www.ipasj.org/IIJME/IIJME.htm
A Publisher for Research Motivation ....
Email: editoriijme@ipasj.org
Volume 2, Issue 7, July 2014
ISSN 2321-6441

Spur Gear Crack Propagation Path Analysis Using Finite Element Method

Mr. Galande S.D [1] , Dr. R. J. Patil [2]

1 PG Student of Mechanical Department in Dr.D.Y.Patil Institute of Engg. & Tech. Ambi, Pune University, Maharashtra India.

2 Principal of Dr .D Y Patil Institute of Engg. & Technology Ambi, Pune University, Maharashtra India

ABSTRACT

An effective gear design balances strength, durability, reliability, size, weight and cost. The engineering structures may fail due to crack, which depends on the design and also on operating conditions in which it operates. It can be avoided by analyzing and understanding the manner in which it originates. It is necessary to develop design guidelines to prevent failure modes considering gear tooth fracture, by studying the crack propagation path in a spur gear. In variety of gear tooth geometry the crack propagation paths are predicted at various crack initiation location. The effects of gear tooth thickness, pitch radius, and tooth pressure angle are considered. The objective of this study was to follow the crack propagation in the tooth foot of a spur gear of milling machine gear box by the Finite Element Method (FEM). In this method Zen-crack software is used to crack detection. The tooth foot crack propagation is a function of Stress Intensity Factors (SIF) that plays a very crucial role in the life span of the gear. An appropriate methodology for predicting the crack propagation path is applied by considering gear tooth behavior in bending fatigue. The results are used to predict/prevent catastrophic rim fracture failure modes from occurring in critical components.

Key words: Spur gear, Zen-crack, Crack propagation path, SIF, FEM

1. INTRODUCTION

Gears are commonly used mechanical components in power transmissions and are frequently responsible for gearbox failures. They are generally design according to standards such as AGMA and DIN. Various types of gears have been developed to perform different functions, the most common of these being spur gears, helical gears, straight and spiral bevel gears, and hypoid gears.. Gears can and do fail in service for a variety of reasons. In most cases, except for an increase in noise level and vibration, total gear failure is often the first and only indication of a problem. Many modes of gear failure have been identified, e.g. Fatigue, impact, wear or plastic deformation. Of these, one of the most common causes of gear failure is tooth bending fatigue. Two kinds of tooth damage can occur under repeated loadings that cause fatigue; namely, the pitting of gear teeth flanks and tooth fracture in the tooth root. Linear Elastic Fracture Mechanics (LEFM) as applicable to gear teeth has become increasingly popular, and it has been developed into a useful discipline for predicting the behavior of cracked gear teeth The stress intensity factors are the key parameters necessary to estimate the characteristics of a crack. Analytical and numerical methods have been used to estimate gear tooth stress intensity factors.

Objectives:

The objectives of the study are:

- The study was to determine the effect of gear rim thickness on crack propagation
- To predict the directions of the crack path either through the gear tooth or gear rim also gear tooth fatigue crack growth is investigated.
- The objective of this study to determine the crack propagation path in the tooth foot of spur gear by using LEFM and FEM.
- Life prediction of cracked spur gear
- Study and define proper optimal weight to life ratio

2. REVIEW OF RELATED LITERATURE

David G. Lewicki and Roberto Ballarini (1996) [1] were performed Analytical and experimental studies to investigate the effect of rim thickness on gear tooth crack propagation. Gears with various backup ratios (rim thickness divided by tooth height) were tested to validate crack path predictions. A computational model for determination of service life of gears in regard to bending fatigue in a gear tooth root is presented by D. Jelaska S. Glodež J. Kramberger S. Podrug[2] in Numerical modeling of the crack propagation path at gear tooth root. Fatigue crack initiation, where it is assumed that the initial crack is located at the point of the largest stresses in a gear tooth root. The simply Paris equation is then used for the further simulation of the fatigue crack growth. M. Guagliano and L.Vergani (2001)[3] explained the effect of crack closure on gear crack propagation. In this paper a computational and

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experimental studies were performed in order to investigate the propagation of cracking in a spur gear tooth. The stress intensity factors were numerically calculated by the definition of weight functions and by finite element analysis. Stanislav Pehan, Janez Kramberger, Joze Flašker, Bostjan Zafosnik (2006)[4] described the Investigation of crack propagation scatter in a gear tooth's root. This paper describes the problem of determining crack initiation location and its influence on crack propagation in a gear tooth's root.

3. MODELLING & ANALYSIS

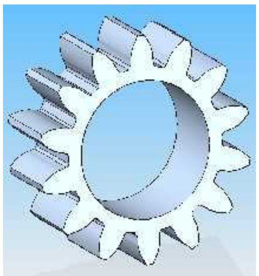
3.1Modeling of Spur Gear:

Solid Edge is 3D CAD parametric feature solid modeling software. Solid Edge is built on a foundation of superior core modeling and process workflows that help engineers design more rapidly by modeling mechanical parts more efficientl

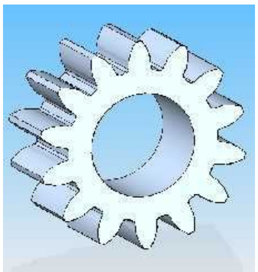
Table 1: Parameters of spur gear

Parameters	Symbol	Gear
Gear Type	-	Standard involutes, full depth teeth
Material	-	42CrMo4
Young's modulus(N/mm2)	E	2.1e5
Width of gear (mm)	L	20
Pressure angle	α	20
Dedendum	hf	1.4M
Addendum	ha	1M
Number of teeth	Z	14
Module, mm	M	3.175
Inner diameter	Φint	24
Total load (N)	F	4200

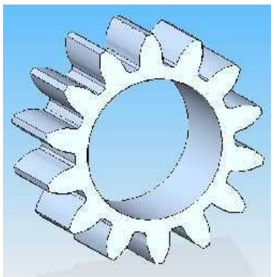
According to parameters enlisted in the table, the spur gear geometry is drawn in the modeling software. The backup ratio is considered as the ratio of rim thickness (b) to tooth height (h).From this we got 8 backup ratio from which we have selected 3 which are optimum 0.8, 0.36, and 0.38



Backup Ratio = 0.8



Backup Ratio = 0.38

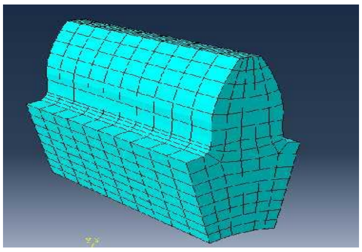


Backup Ratio = 0.38

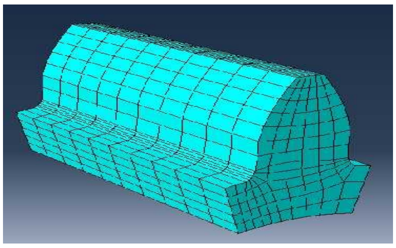
Figure 1: Gear Model

3.2 Preprocessing (Abaqus/CAE): In this stage you must define the model of the physical problem and create an Abaqus input file.

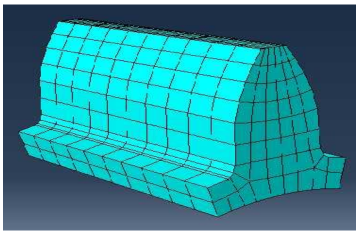
3.3 Mesh Generation: The Standard Spur gear is meshed with the 8 nodded brick elements. There is linear C3D8 family available in the Abaqus environment.



Meshed Model Backup ratio = 0.38



Meshed Mode Backup ratio = 0.36



Meshed Model of Backup ratio = 0.8

Figure 2 Meshed Model

3.4 Boundary Conditions

In structural analyses, boundary conditions are applied to those regions of the model where the displacements and/or rotations are known. Such regions may be constrained to remain fixed (have zero displacement and/or rotation) during the simulation or may have specified, nonzero displacements and/or rotations.

- Total Force, F = 4200 N
- Density = 7830 kg/m3
- Crack depth = 1 mm
- Crack position (ψ) = 350
- rack propagation angle (θ) = 900 & 00
- ymmetry B. C. applied to outer surface of the teeth.

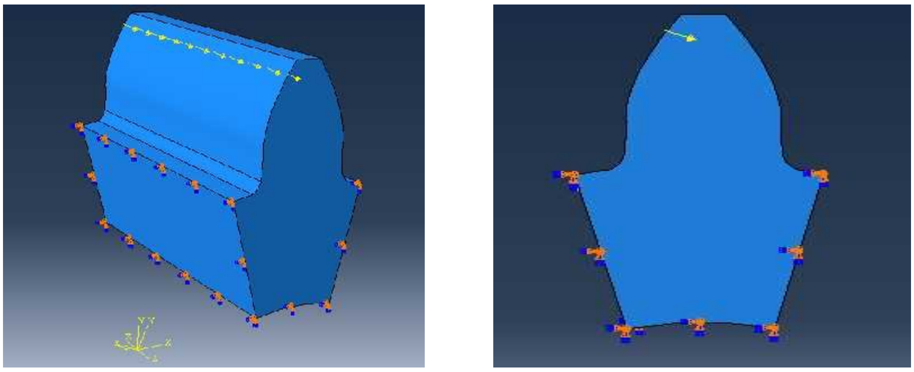


Figure 3: Boundary Conditions applied to teeth

3.5 Simulation (Abaqus /Standard)

The simulation, which normally runs as a background process, is the stage in which Abaqus/Standard or Abaqus/Explicit solves the numerical problem defined in the model. Examples of output from a stress analysis include displacements and stresses that are stored in binary files ready for post processing

3.6 Post processing (Abaqus /CAE)

We can evaluate the results once the simulation has been completed and the displacements, stresses, or other fundamental variables have been calculated The Visualization module, which reads the neutral binary output database file, has a variety of options for displaying the results, including color contour plots, animations, deformed shape plots, and X–Y plot

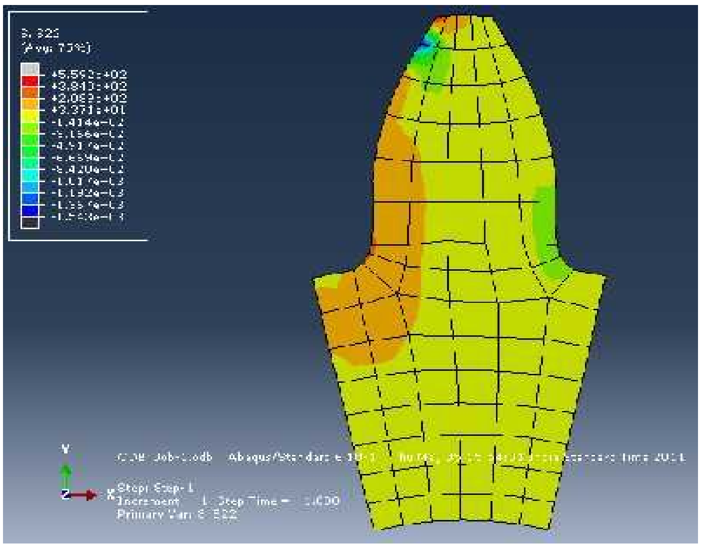


Figure 4: Maximum Principle Stresses

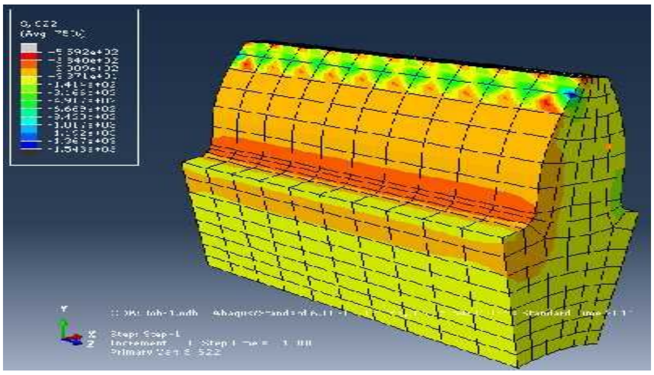


Figure 5 : Maximum Principle Stresses in 3D

3.7 Zencrack input data :

A minimum of two input files is required for any Zencrack analysis:

- The uncracked mesh file
- The Zencrack input file

The method used by Zencrack to generate a cracked mesh is the replacement of one or more brick elements in an uncracked mesh by crack-blocks. These crack-blocks are stored as unit cubes and each contains a section of crack front. The crack starts propagating through the gear tooth or gear rim in Zencrack. Following figures shows the path of propagation of crack for different backup ratios

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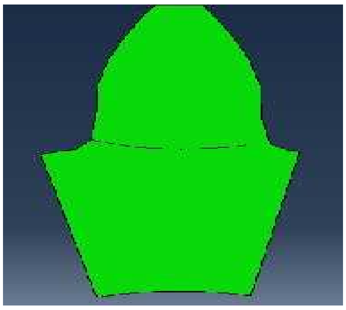
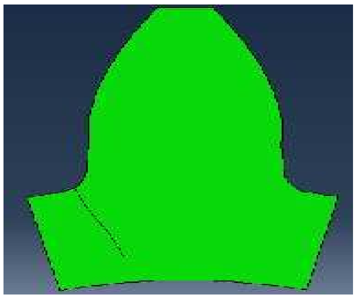
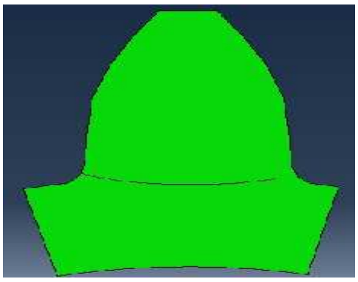
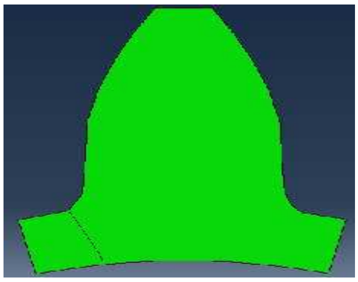



Backup ratio = 0.8, ϴ = 80^{0}(Case1) **Backup ratio = 0.38, ϴ = 10^{0}(Case2)**

Backup ratio = 0.38, ϴ = 80^{0}(Case3) **Backup ratio = 0.36, ϴ = 80^{0}(Case4)**

Figure 6: Gear with crack Propagation

4. RESULTS

According to this study, that for a backup ratio (defined as rim thickness divided by tooth height) of m & 0.38 (critical case), the crack propagation for the period of service has the tendency to destroy the rim when the initial crack angle is close to the vertical (θ = 00,200), and the cracks propagated through the tooth when they started nearly the horizontal direction (θ = 700, 900). For backup ratios of m > 0.38, the analysis predicted cracks that would propagate through the teeth and not the rims. For m < 0.38, the analysis predicted cracks that would propagate through the rim. A major emphasis was to determine the direction in which cracks grew, through the teeth or through the rim. Gear tooth crack propagation was simulated using a FEM Software Abaqus and Zencrack which used the principles of LEFM. A crack was propagated along different paths, according to the various backup ratios (m), and the initial crack angle incorporated in the tooth foot. Therefore, from a critical value of m (mc situated between 0.5 and 0.3 and equal to 0.38

in our analysis), the initial crack has the tendency to propagate through either the tooth or the rim according to the value of m.

- If m > mc (m > 0.38) propagation leads to the tooth deterioration
- If m< mc (m < 0.38) propagation causes deterioration of the gear body

The stress intensity factors from Zencrack were used to calculate fatigue crack propagation cycles. Following graphs are plotted for crack depth Vs Number of cycles for different back up ratios

Table 2: Optimal weight to life ratio

Backup Ratio	Number of Cycles	Weight (Kg)	Weight/Life Ratio
0.8	8.2 x 107	0.189	2.300 x 10-9
0.7	4.2x 107	0.150	3.57 x 10-9
0.6	3.1 x 106	0.130	4.19 x 10-8
0.5	8.5 x 106	0.110	1.29 x 10-8
0.4	6.4 x 106	0.095	1.48 x 10-8
0.38	2.8 x 106	0.091	3.25 x 10-8
	8 x 104	0.091	1.13 x 10-6
0.36	7.5 x 104	0.089	1.18 x 10-6

5. CONCLUSION

In this project our aim was to find crack propagation from the above result we can say that for backup ratios of >0.38, the analysis predicted cracks that would propagate through the teeth and not the rims. For m < 0.38, the analysis predicted cracks that would propagate through the rim. Also for the backup ratio 0.38 the weight of the rim is reduced up to 0.091it is lower than the weight of Backup ratio 0.8 also at this backup ratio we have maximum life. hence the life cycle of cracked spur gear also increased

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AUTHOR

Galande Swapnil D. received B.E. from SIT, Lonavala & Persuing ME (Machine Design) from DYPIT, Ambi from Pune University.