Crack Propagation Path In The Tooth Foot Of Spur Gear By Using LEFM And FEM

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Abstract - Commonly used mechanical components in power transmissions are the gears, and which are frequently responsible for gearbox failures. The reduction of the overall weight is a common design objective for gears in helicopter power transmissions. Therefore, in order to reach this goal, some gear designs use thin rims. Too thin rims may lead to bending fatigue problems. A crack which may propagate through a tooth or into the rim, depending on the geometry and load on the gear, or the severity defect from fabrication and installation. AGMA and DIN are the standards which are generally use to design the gears. In this paper crack propagation path in the tooth foot of spur gear by using LEFM & FEM and life prediction is studied.

Index Terms - *Gear, LEFM, FEM*

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I. INTRODUCTION

Gears are commonly used machine component in the industrial machinery, automobiles, and aerospace and also in domestic equipments. Gears are commonly used mechanical components in power transmissions which are frequently responsible for gearbox failures. It is difficult to diagnose gear cracks in early stages by using available methods as before detecting the damage; significant damage must be present. The provocation of a crack would alter the stiffness of the tooth mesh. The stiffness of a gear tooth during meshing, controls the load sharing, fatigue resistance, vibration and noise properties of the geared system.

Two kinds of tooth damage can occur due to repeated loadings that cause fatigue; which may be the pitting of gear teeth flanks and tooth fracture in the tooth root. The most undesirable damage that can occur in gear units is the crack in the tooth foot as it often makes the operation of the gear unit impossible. The aim of the maintenance is to keep a gear-unit or technical system in the most suitable working condition and to discover, diagnose, foresee, prevent, and/or to eliminate damage. Obviously, the purpose of modern maintenance is not only to avoid failures but also to define the stage of gear degradation where there is significant potential for a sudden system operation failure. Gears used in helicopter power transmissions are mainly designed to reduce the overall weight. Therefore, in order to meet this goal, some gear designers use thin rims. Rims that are too thin, however, may lead to bending fatigue problems. Depending on the geometry and load on the gear, a crack may propagate through a tooth or into the rim or the severity defect form during fabrication and installation. In aircraft applications, a crack that propagates through a rim would be catastrophic, leading to disengagement of a rotor or propeller, loss of an aircraft, and possible fatalities. 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.

II. LITERATURE REVIEW

Basim Mohammed Fadhil [1] has presented paper on “Crack path prediction of Gear Tooth with different Pressure Angles - Numerical study” in this paper A numerical model study was performed to investigate the influence of the gear pressure angle associated with rim thickness on gear tooth crack initiation and propagation besides the fatigue life. Three values of pressure angles (15o, 20o, and 22º are taken in account associated with three values of rim thickness. A finite element programs FRANC2Dand ABAQUS were used to simulate gear tooth initiation and propagation. The analysis used principles of linear elastic mechanics. FRANC program had a unique feature to automated crack propagation using automated re-meshing scheme. The computed stress intensity factors used for determine crack propagation direction with a simple Paris equation, fatigue life, has been calculated. The results show that the gear pressure angle associated with rim thickness has a significant effect on the crack initiation position and crack propagation path in addition of fatigue life.

T. Osman, Ph. Velex [2] has presented paper on a model for the simulation of the interactions between dynamic tooth loads and contact fatigue in spur gears in this paper main objective is to study the possible interactions between contact fatigue and Dynamic tooth loads on gears. A specific 3D dynamic gear model is combined to contact fatigue models accounting for crack initiation and propagation. The numerical findings compare well with the experimental evidence from a back-to-back test rig. Three characteristic points on a tooth profile are analyzed and it is shown that contact fatigue on spur gears clearly depends on dynamic phenomena. Finally, the introduction of profile relief is discussed and its positive influence on the risk of failures at engagement is emphasized.

Ananda Kumar Eriki, Ravichandra R , Mohd.EdilanMustaffa[3]have beenpresented paper on "Spur Gear Crack Propagation Path Analysis Using Finite Element Method" in this they have proposed that An effective gear design balances strength, durability, reliability, size, weight and cost. However unexpected gear failure may occur even with adequate gear tooth design. Failure of the engineering structures was caused by crack, which depends on the design and operating conditions.

Srđan Podrug , Srečko Glodež , Damir Jelaska[4] has been presented paper on "Numerical Modeling of Crack Growth in a Gear Tooth Root" in this they have proposed A computational model for determination of crack growth in a gear tooth root was presented. Two loading conditions were taken into account: (*i*) normal pulsating force acting at the highest point of the single tooth contact and (*ii*) the moving load along the tooth flank. In numerical analysis it has been assumed that the crack was initiated at the point of the largest stresses in a gear tooth root. The Coffin-Manson relationship is used to determine the number of stress cycles Ni required for the 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, where required material parameters have been determined previously by the appropriate test specimens.

S. Zouari, M. Maatar ,T. Fakhfakh,M, Haddar [5] in following spur gear crack propagation in the tooth foot by finite element method described crack propagation in the tooth foot of a spur gear by using Linear Elastic Fracture Mechanics (*LEFM*) and the Finite Element Method (*FEM*). 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. A two- dimensional quasi-static analysis is carried out using a program that determines the gear geometry, coupled with the Finite Element Code (*ANSYS*). The study estimates the stress intensity factors and monitors their variations on the tooth foot according to crack depth, crack propagation angle, and the crack position.

Göncz, P.; Gubeljak, N.; Potocnik, R. & Glodež, S [6] presented paper on Fracture mechanics parameters of 42CrMo4 steel this paper describes the experimental determination of fatigue crack growth parameters C and m for high strength low-alloy steel 42CrMo4. For this purpose several middle tension specimens of different hardness were subjected to cyclic loading on a servo hydraulic fatigue test machine during which the fatigue crack propagation was observed. From experimental measurements the parameters of the Paris Law were determined and they are presented as a function of the Rockwell hardness of the 42CrMo4 steel. Additionally, the fracture toughness of the specimens was measured. With these fracture mechanics parameters the fatigue crack growth life (N) of machine elements made of 42CrMo4is covered. In this paper the determination of the Paris Law parameters C and m forth case of 42CrMo4 steel is presented.

Stanislav Pehan, Janez Kramberger, Joze Flašker, Bostjan Zafosnik[7] 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. Three different load positions on the gear tooth's flank were considered for this investigation of crack initiation and propagation. A special test Device was used for the single tooth test. It can be concluded from the measurements that a crack can be initiated at very different locations in a tooth's root and then propagate along its own paths. A numerical investigation into a crack initiation's position and its influences on its propagation were carried out within the framework of linear fracture mechanics. The influence of a tooth's load position, the geometry of the tooth's root, and the influence of non-parallel load distribution on the tooth's flank were considered when investigating the crack initiation's position. Results show that linear fracture mechanics can be used for determining crack propagation, if better initial conditions for crack initiation are considered.

S. Zouri, M Maatar, T. Fakhfakh and M. Haddar [8]performed a three dimensional analyses by finite element method of spur gear and check the effect of cracks in the teeth foot on mesh stiffness. In this paper, a finite element method with three dimensional surveys is presented. The effect of crack dimension and the direction of crack propagation, in the teeth foot, on mesh stiffness are studied. For spur gears, mesh stiffness is affected in meaningful manner by the presence of foot crack of one or more teeth. This study is an attempt to estimate the effect of crack size, position, and direction on the spectrum of gear mesh stiffness.

M. Guagliano and L.Vergani [9] explained the effect of crack closure on gear crack propagation. In this paper a computational and 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. The influence of the hardness and the residual stress was evaluated and a computational procedure, based on crack tip opening displacement, was defined in order to assess the crack closure effect. Different propagation laws were adopted and life predictions were made. Experimental results were obtained by using special equipment with which it is possible to carry out fatigue tests on gear teeth.

David G. Lewicki and Roberto Ballarini [10] performed Analytical and experimental studies to investigate the effect of rim thickness on gear tooth crack propagation. The goal was to determine whether cracks grew through gear teeth or through gear rims for various rim thicknesses. A finite element based computer program (*FRANC, Fracture Analysis Code*) was used to simulate gear tooth crack. The analysis used principles of linear elastic fracture mechanics (LEFM). Quarter-point, triangular elements were used at the crack tip to represent the stress singularity. The program had an automated crack propagation option in which cracks were grown numerically using an automated re-meshing scheme. Crack tip stress intensity factors were estimated to determine crack propagation direction. Gears with various backup ratios (rim thickness divided by tooth height) were tested to validate crack path predictions. Gear bending fatigue tests were performed in a spur gear fatigue rig.

III. PROBLEM DEFINITION AND OBJECTIVE

Problem Definition:

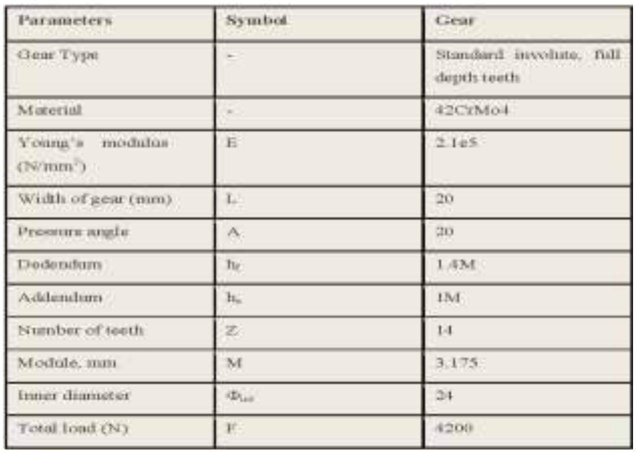
A common design objective for gears in helicopter power transmissions is to reduce the overall weight. Therefore, in order to reach this goal, some gear designs use thin rims. Rims that are too thin, however, may lead to bending fatigue problems. A crack may propagate through a tooth or into the rim, depending on the geometry and load on the gear, or the severity defect from fabrication and installation. In aircraft applications, a crack that propagates through a rim would be catastrophic, leading to disengagement of a rotor or propeller, loss of an aircraft, and possible fatalities.

Objective:

1. This study is to determine the crack propagation path in the tooth foot of spur gear by using LEFM and FEM methods.
2. Life prediction of cracked spur gear
3. Study and define proper optimal weight to life ratio.

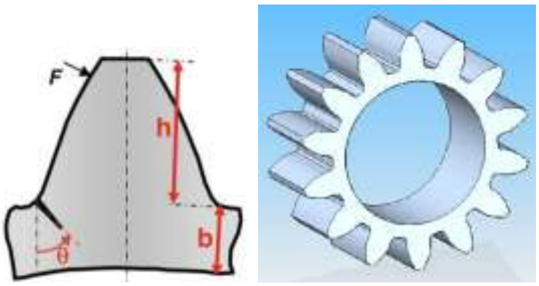
Modelling of Spur Gear:

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 efficiently. To draw gear geometry in any modeling software is very difficult task. So, we have chosen simple middle end software like Solid Edge for geometry modeling. Following table contained the different parameters and physical properties of spur gear used



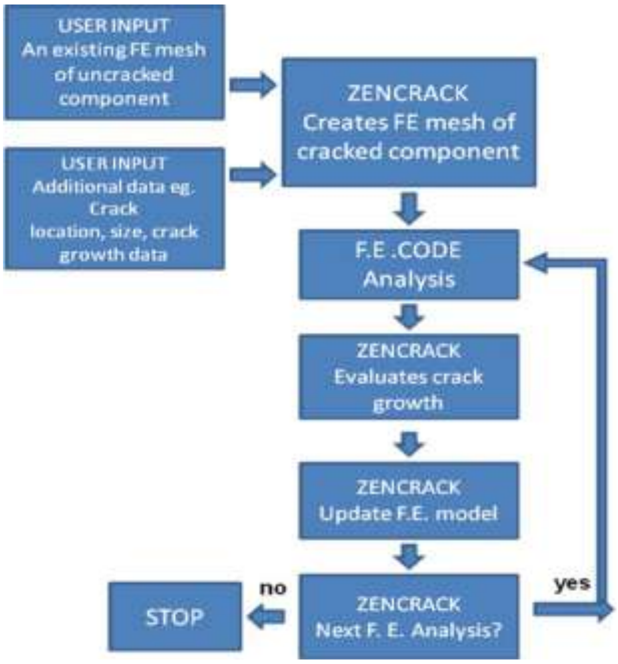
Parameters	Symbol	Gear
Gear Type	-	Standard involute, full depth teeth
Material	-	42CrMo4
Young's modulus (N/mm^2)	E	2.1e5
Width of gear (mm)	L	20
Pressure angle	A	20
Dedendum	h_f	1.4M
Addendum	h_a	1M
Number of teeth	Z	14
Module, mm	M	3.175
Inner diameter	Φ_{int}	24
Total load (N)	F	4200

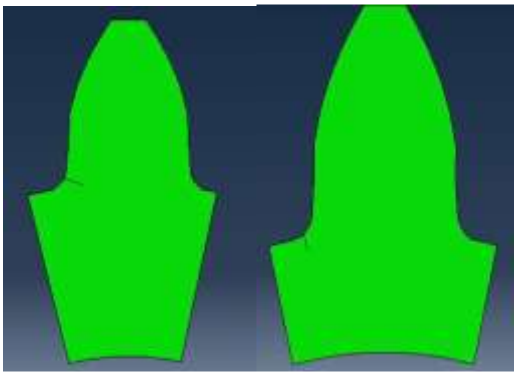
$$\text{Backup Ratio} = \frac{\text{rim thickness}}{\text{tooth height}}$$



Geometric Parameters Backup ratio = 0.36

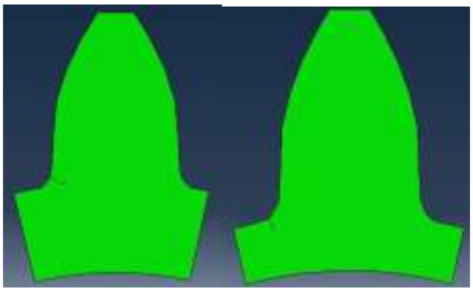
FEM procedure:





Backup ratio = 0.8, θ = 80^0
(Case 1)

Backup ratio = 0.38, θ = 80^0
(Case 2)



Backup ratio = 0.37, θ = 80^0 Backup ratio = 0.36, θ = 80^0
(Case 3) (Case 4)
Crack propagation of 1mm in various spur gear models

Results from Software Based:

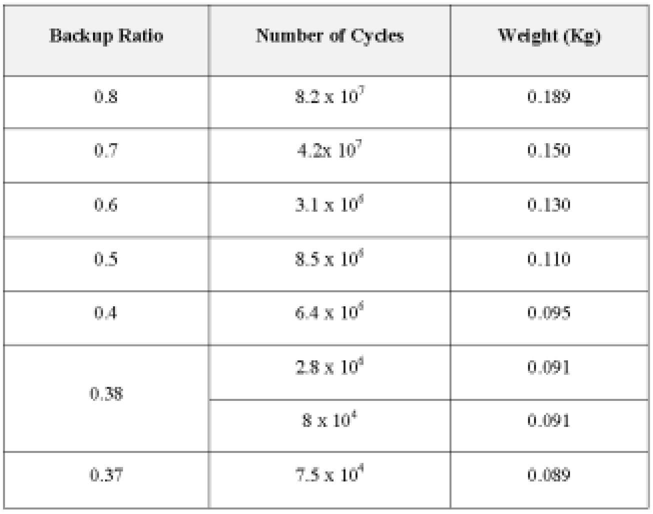
According to this study, that for a backup ratio (defined as rim thickness divided by tooth height) of m & 0.38 (critical case), the crack propagation for the period of service has the tendency to destroy the rim when the initial crack angle is close to the vertical (*θ = 00, 200*), and the cracks propagated 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. Form < 0.38, the analysis predicted cracks that would propagate through the rim. This study analyzed the effects of the depth, orientation, and position of the crack on the stress intensity factors (KI and KII). A dominant opening mode, in all orientations, has been observed. However, this preponderance passes when the crack propagation seems to destroy the tooth that is to say for θ = 90.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 Abacus and Zen crack 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 to0.38 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. An abrupt stop of the movement transmission is generated, which is very harmful in certain cases and especially in the aerospace domain, which can even lead to human casualties. Therefore, we have to intervene in the suitable time before any serious damage can occur.

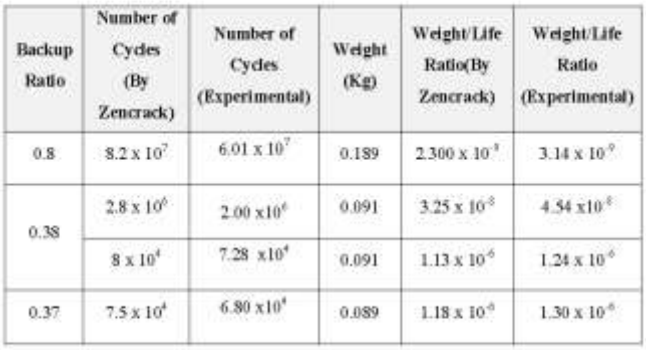
If m< mc (m < 0.38) propagation causes deterioration of the gear body. First, the vibration and noise are generated, driving thereafter to the interference phenomenon (braked movement). Thus, the mechanism of propagation is slower in this case.

Zencrack output Result:



Backup Ratio	Number of Cycles	Weight (Kg)
0.8	8.2 x 10^7	0.189
0.7	4.2x 10^7	0.150
0.6	3.1 x 10^6	0.130
0.5	8.5 x 10^6	0.110
0.4	6.4 x 10^6	0.095
0.38	2.8 x 10^6	0.091
	8 x 10^4	0.091
0.37	7.5 x 10^4	0.089

Optimal weight to life ratio:



Backup Ratio	Number of Cycles (By Zencrack)	Number of Cycles (Experimental)	Weight (Kg)	Weight/Life Ratio(By Zencrack)	Weight/Life Ratio (Experimental)
0.8	8.2 x 10^7	6.01 x 10^7	0.189	2.300 x 10^{-9}	3.14 x 10^{-9}
0.38	2.8 x 10^6	2.00 x10^6	0.091	3.25 x 10^{-8}	4.54 x10^{-8}
	8 x 10^4	7.28 x10^4	0.091	1.13 x 10^{-6}	1.24 x 10^{-6}
0.37	7.5 x 10^4	6.80 x10^4	0.089	1.18 x 10^{-6}	1.30 x 10^{-6}

IV. FUTURE SCOPE

The model is used to determine the crack propagation path, fatigue life and weight to life ratio. The crack position (ψ) considered in this analysis is constant but, the crack propagation angle is changing. For future study one can change the crack position (ψ) along with the crack propagation angle (θ). So that, the model that can be optimized twosome extent. There are various approaches of fracture mechanics i.e. CTOD approach, Direct residual method, J-Integral etc. The model can be solved by using any of these techniques and compare the results obtain from various approaches

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