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FINITE ELEMENT ANALYSIS OF SPUR GEAR CRACK PROPAGATION FOR OPTIMAL WEIGHT TO LIFE RATIO

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Abstract- **The objective behind this study is to follow the crack propagation in the tooth foot of a spur gear by using Finite Element Method and the Linear Elastic Fracture Mechanics. The tooth foot crack propagation is a function of Stress Intensity Factors that plays a very important role in the life span of the gear. The study determine the stress intensity factors and monitors their variations on the tooth foot according to crack depth, crack propagation angle, and the crack position. A two-dimensional quasi-static analysis is carried out using a program that determines the gear geometry, coupled with the Finite Element Code and Zencrack fracture mechanics software. An appropriate method 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- Crack propagation path, Spur gear, SIF FEM

I. 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. 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. The most undesirable damage that can occur in gear units is the crack in the tooth foot as it often makes by Shree 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. A common design objective for gears in helicopter power transmissions is to reduce the overall weight. Therefore, in order to help meet 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. 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. Many authors have used LEFM for the calculation of tooth bending strength, using numerical procedures such as finite element method (FEM) and boundary element method (BEM). 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. Based on the latter, rack growth and gear life predictions have been investigated. In addition, gear crack trajectory predictions have been addressed in a few studies.The phenomenon of gear tooth crack propagation has, amply, been the center of interest for much research concerning the mechanical and dynamic behaviors of gears. Some analytic and experimental studies have determined the direction of the gear tooth crack propagation.

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II. LITERATURE SURVEY

Z. Chen, et. al focused on that the crack openings tress equation is expressed as a second- order non line a auto regressive model with the steady-state crack openings tress being an input excitation. This equation can capture the effects of over load or under load and reverse plastic flow; moreover, it can explain the retardation effect of crack growth [1]. S. Zaurar, et. al focused on an analytical mesh stiffness model of spur gear with tooth root crack propagating along both tooth width and crack depth is proposed in this paper. It is validated by comparison with the FEA results. At the same time, effects of gear tooth crack propagating along tooth width and depth on gear mesh stiffness are investigated quantitatively[2]. Fakher. Charri, focused on at higher levels of 40–50% crack length, Cumulative reduction in mesh stiffness (CRI) is higher for predicted curved crack path than the straight crack path in almost all the cases (I, II, III) of double and single tooth pair contact in mesh. At lower levels of 10–20% crack length, the change in CRI is almost similar due to the fact that the separations of crack trajectories (difference in crack intersection angle) are minimal [3]. Wu S, Zuo KJ, et.al , focused on that the numerical model used to predict the fatigue crack growth in a gear tooth root is presented in this paper[4]. A. Belsak et. al focused on that effect of gear rim thickness on the fatigue crack propagation in a gear tooth root and formation of a crack path is also studied [5]. David G. Lewicki, Using the numerical procedure described above the predictions of crack propagation lives and crack paths in regard to the gear tooth root stresses are obtained. They are significantly different in comparison to some simplified models, which have been published previously [6].

From all above literature survey we hav conclude that all gears crack propagation prediction is done by two ways first is by increasing height of tooth or rim i.e. by varying backup ratio and another is by changing the angle of crack path. The results are used to predict/prevent catastrophic rim fracture failure modes from occurring in critical components.

III. Problem Statement

Gear models with backup ratio one and less than one, increased fillet and increase in pressure angles are only considered here for investigation due to the fact that for low initial crack intersection angles, all of them slightly increases the chances of tooth fracture. A detailed comparison has been made for different gear parameters like pressure angle, fillet radius and backup ratio to quantify the percentage correction in the values of total effective mesh stiffness. A percentage cumulative reduction index (CRI) has been proposed for better quantification and visualization of the effect of different gear parameter and crack length on mesh stiffness values.

IV. OBJECTIVE

1. To study of the pattern of gear tooth crack growth under variable-amplitude loading.
2. A finite element based computer program simulated gear tooth crack propagation.
3. Analytical and experimental studies were performed to investigate the effect of rim thickness on gear tooth crack propagation.
4. To develop design guidelines to prevent failure modes considering gear tooth fracture,by studying the crack propagation path in a spur gear .

V. Theoretical Calculations

Material: For 42CrMo4 Alloy Steel

Table : Parameters of Spur Gear

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	α	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

Calculations for 42CrMo4 Alloy Steel

Module (m) = Pitch circle diameter/Number of teeth

1.175= D/14

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Pitch Circle Diameter D = 44.45 mm.

Addendum = 1M = 1x 3.175 = 3.175 mm.

Deddendum = 1.4 M =1.4 x 3.175 = 4.445 mm.

Addendum Circle Diameter = 44.45 + 2 x 3.175 = 50.8 mm

Deddendum Circle Diameter = 44.45 - 2 x 4.445 = 35.56 mm

Circular pitch = PC = (π x pitch circle diameter) /Number of teeth on wheel

Pc = (π x 44.45) /14

Pc = 9.96 mm.

Backup Ratios (m),

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

m1 = 5.7/7.12 = 0.8

m2 = 5/7.12 = 0.7

m3 = 4.3/7.12 = 0.6

m4 = 3.56/7.12 = 0.5

m5 = 2.84/7.12 = 0.4

m6 = 2.71/7.12 = 0.38

m7 = 2.56/7.12 = 0.36

Assumptions:
Tooth foot crack propagation = f (Stress Intensity factor)
Study estimates SIF and monitors their variations on the tooth foot according to-
Crack initiation which is localized in the tooth foot for $\Psi = 35^0$, on the fillet region, is the position of the greatest tensile stress for the solid gear.
Crack propagation angle (Θ) is changing from 0^0 to 90^0.

Crack depth (a) in mm.

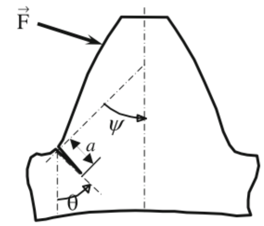

Fig. 1 Geometric feature of the crack
Process of Finite Element Analysis

Model of spur gear is created in Solid Edge software then structural analysis is performed in Abaqus simulia software. The Finite element method is numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. Because of its diversity and flexibility as an analysis tool, it is receiving much more attention in engineering schools and industries. In more engineering situations today, we find that it is necessary to obtain approximate solutions to problems rather than exact closed form solutions. The following is the flowchart of finite element analysis technique performed on the spur gear.

V. FLOWCHART

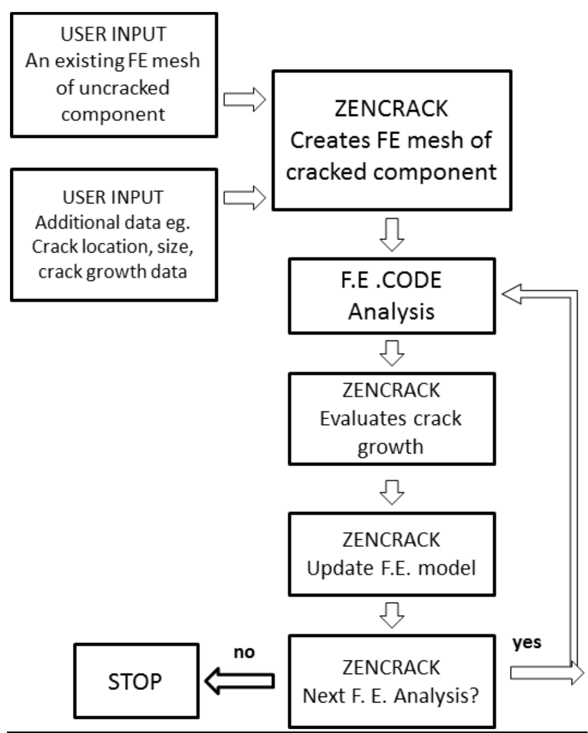

Fig.2. Flowchart

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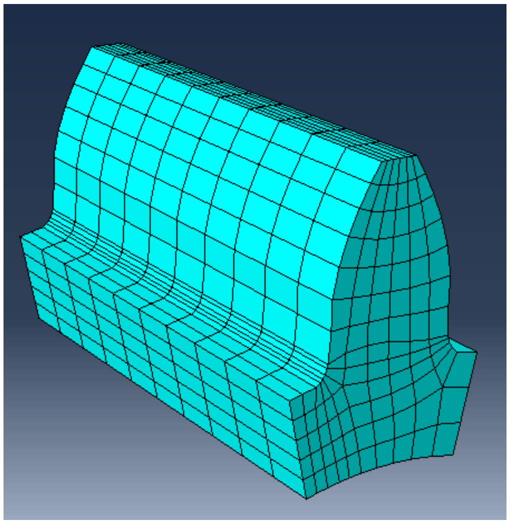
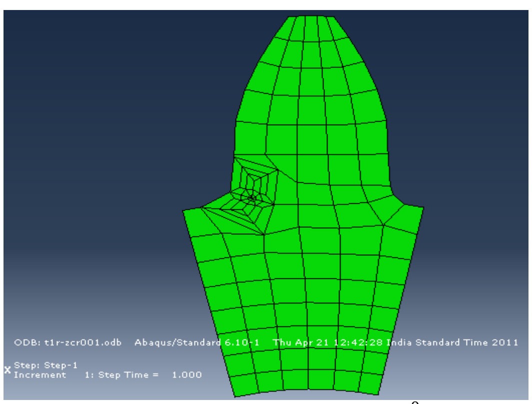
He mesh models are shown below. The boundary conditions applied on the spur gear to determine the location of maximum stress. Then at maximum stress location, the crack of 0.5 mm is introduces with the help of Zencrack software.



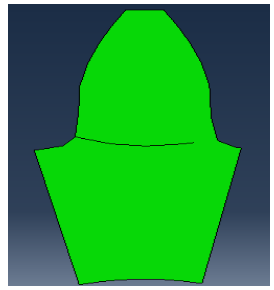
Mesh Model

The crack mesh model is provided at the images below.

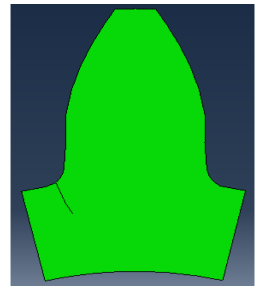


Crack mesh spur gear Θ= 80^0

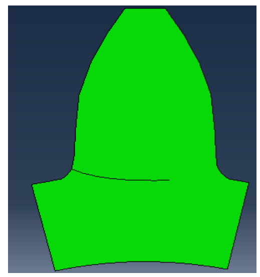
The Zencrack run is finished after performing number of iterations based on calculation of SIFs near the crack tip. The crack starts propagating through the gear tooth or gear rim in Zencrack. Following figures shows the path of propagation of crack for different backup ratios.



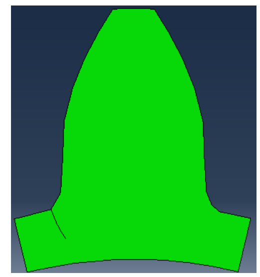
Backup ratio = 0.8, $\Theta = 80^0$



Backup ratio = 0.8, $\Theta = 80^0$



Backup ratio = 0.38, $\Theta = 80^0$



Backup ratio = 0.36, $\Theta = 10^0$

VI. RESULT AND DISCUSSION

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.

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. 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

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generated, driving thereafter to the interference phenomenon (braked movement). Thus, the mechanism of propagation is slower in this case.

VII. CONCLUSION

Following table shows the optimal weight to life ratio for each backup ratio. From the values, calculated in the table 4 shows that, the backup ratio should be greater than 0.38. The weight to life ratio for backup ratio 0.38 is 3.25×10^{-8} and 1.13×10^{-6}. For aerospace applications, weight is very important factor. So from results it is clear that, the ratio should be less than or equal to 3.25×10^{-8}.

Backup Ratio	**Number of Cycles**	**Weight (Kg)**	**Weight/Life Ratio**
0.8	8.2×10^{7}	0.189	2.300×10^{-9}
0.7	4.2×10^{7}	0.150	3.57×10^{-9}
0.6	3.1×10^{6}	0.130	4.19×10^{-8}
0.5	8.5×10^{6}	0.110	1.29×10^{-8}
0.4	6.4×10^{6}	0.095	1.48×10^{-8}
0.38	2.8×10^{6}	0.091	3.25×10^{-8}
	8×10^{4}	0.091	1.13×10^{-6}
0.37	7.5×10^{4}	0.089	1.18×10^{-6}

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