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Analysis of crack in a Tooth of Spur Gear Using Finite Element Analysis and Remedial action

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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.*

Keywords- *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 [1]. 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. [1]. 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 [2]. 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). [3] 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 [4].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 [5].

II. 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.

III. 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 .

Theoretical Calculations [9]

For Spur gear of 42CrMo4 Alloy Steel

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

$$m_1 = \frac{14.24}{7.12} = 2$$

$$m_2 = \frac{7.12}{7.12} = 1.0$$

$$m_3 = \frac{5.696}{7.12} = 0.8$$

$$m_4 = \frac{4.984}{7.12} = 0.7$$

$$m_5 = \frac{4.272}{7.12} = 0.6$$

$$m_6 = \frac{3.56}{7.12} = 0.5$$

$$m_7 = \frac{23.496}{7.12} = 0.3$$

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.

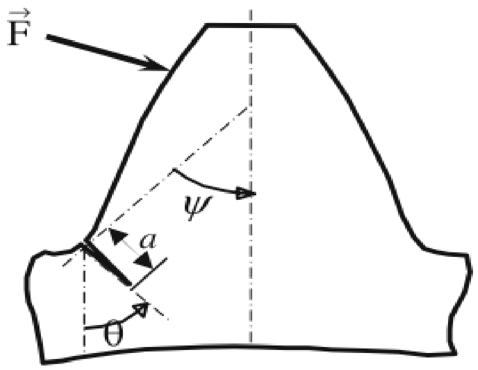


Fig. 1 Geometric feature of the crack Process of FEA

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.

III. IMPLEMENTATION

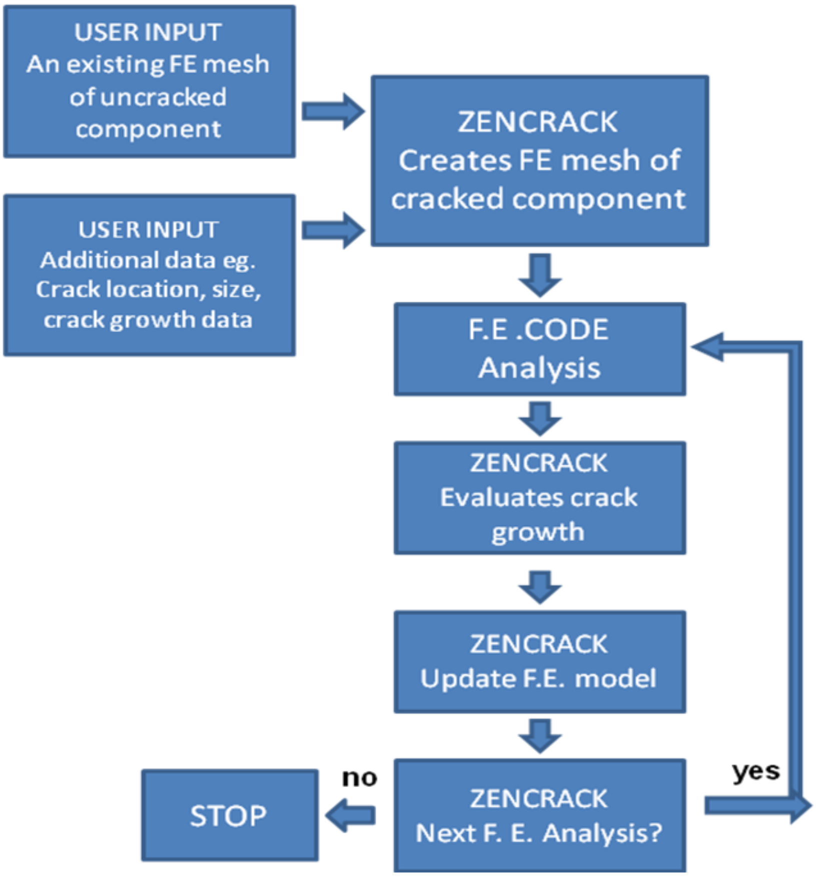
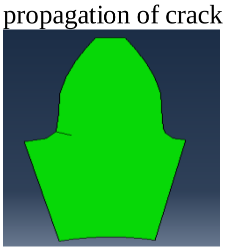
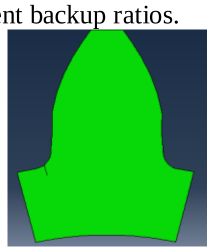
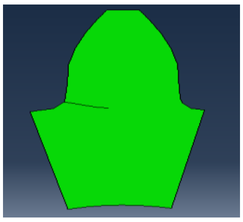


Fig.2. Flowchart of Zencrack analysis for Spur Gear

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 = 2, $\Theta = 80^{0}$


Backup ratio = 0.5, $\Theta = 80^{0}$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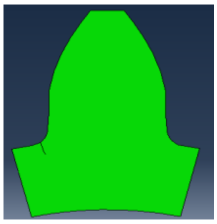
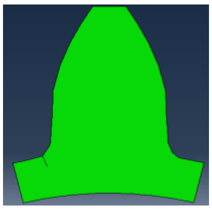
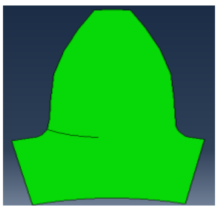

Backup ratio = 0.5, $\Theta = 10^{0}$


Backup ratio = 0.5, $\Theta = 80^{0}$


Bckup ratio = 0.3, $\Theta = 80^{0}$


Backup ratio = 0.5, $\Theta = 80^{0}$

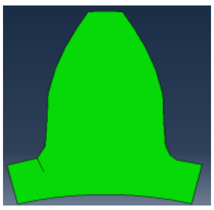
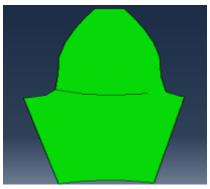
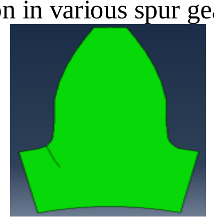
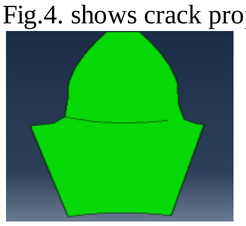

Backup ratio = 0.3, $\Theta = 10^{0}$

Fig.3. shows crack propagation in various spur gear model

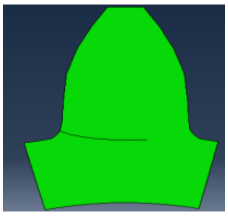
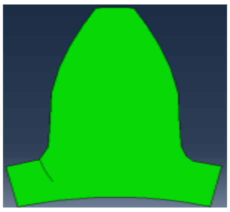
Fig.4. shows crack propagation in various spur gear model


Backup ratio = 2, $\Theta = 80^{0}$


Backup ratio = 0.5, $\Theta = 10^{0}$

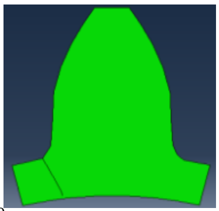

Backup ratio = 2, $\Theta = 80^{0}$


Backup ratio = 0.3, $\Theta = 10^{0}$

Backup ratio = 0.5, $\Theta = 80^0$ Backup ratio = 0.3, $\Theta = 10^0$

Fig 5. shows crack propagation in various spur gear model

Backup ratio = 0.5, $\Theta = 80^0$ Backup ratio = 0.3, $\Theta = 80^0$

Fig.6. shows crack propagation in various spur gear model

V. RESULT

5.1 Optimal weight to life ratio of Finite Element Analysis

Backup Ratio	Number of Cycles	Weight (Kg)	Weight/ Life Ratio
2	83e6	0.3	3.6144e-9
1	43e6	0.170	3.9534e-9
0.8	32e5	0.150	4.687e-8
0.7	86e5	0.140	1.279e-8
0.6	64e5	0.12	1.875e-8
0.5	29e5	0.1	3.4482e-8
	8e4	0.1	1.25e-6
0.3	75e3	0.09	1.20e-6

.

VI. CONCLUSION

Following table shows the optimal weight to life ratio for each backup ratio. From the values, calculated in the table 5.1 shows that, the backup ratio should be greater than 0.5. The weight to life ratio for backup ratio 0.5 is 3.4 x $10^{e-8}$and 1.25 x e-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 3.44e-8.

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