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Finite Element Analysis of Fatigue Crack Growth Rate of Spur Gear Tooth

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Abstract—Spur gear is the main source of power transmission in different gearbox system. The bending fatigue is a common mode of fatigue failure of a spur gear. It means that progressively damage of spur gear tooth and leads to complete failure of a spur gear. The initial crack is locate at the point where continuously cyclic stress is acting on spur gear tooth. There are two types of crack first one crack initiation and second crack propagation. If crack created on the gear tooth root then it goes on increasing. i.e. crack growth till complete break of tooth in two parts. The completely bending fatigue of spur gear is mainly divided into two parts crack initiation period and crack propagation period. Under the range of operating conditions, were Analytical performed by using standard specimens which were made up of structural steel. Mechanical APDL 17.2 is use for simulation. The crack propagation rate is determined by plotting the graph of the crackgrowth (da) versus cycles (dN). The complete service life of a spur gear can be then determine from no. of stress cycles required for fatigue initiations and no. of stress cycles for a crack propagate. The functional relationship between the stress intensity factor (ΔK) and crack length(da) which is use for determination of the required number of loading cycles (N) for a crack propagation from the initial to the critical length. The service life of spur gear can be found out using Paris Law which isbase on crack propagation rate and difference of Stress Intensity Factor**.**

Index Terms—FCGR, Service Life,Standard Specimen,Paris Law,SIF,Crack Length

1 Introduction

Till today the most of the gears are failed because of crack growth at the root of gear. It is required to know the facts about gear failures. It is finding that different methods of Crack propagation analysis of gears are investigated by different research. Thus this research can give more information to industrial professionals and new researchers. Research in this field is continuously going on, and still some scope is there.

Gear is used to transmit force and motion from one shaft to another. The design and function of gears are closely associated, since gears are design for a specific function. The general types of failure modes in gear teeth include fatigue, impact, wear and plastic deformation, of these, the most common cause of gear failure is tooth bending fatigue.

It is necessary that the gears should function properlywithout failure for particular applications and stipulated life cycles. The gear failure will cause partial or complete failure of the mechanical systems.
The fracture mechanics approach is used for analysis of bending fatigue failure. It will predict the remaining useful life of gears due to crack propagation.

2.Literature Review

[1]Carried out the research work on the Bending fatigue and contact fatigue characteristics of carburized gears. In this different bending and fatigue characteristic are studied in order to aim to reduce production costs and improve gear quality and reliability. The results of this concluded that single tooth bending fatigue, and contact fatigue tests on production gears manufactured from EN39B steel (steel A), and experimental steels B, C and D.**[2]**.presented the work on the analytical model for mesh stiffness calculation of spur gear pair with on uniformly distributed tooth root crack. In this paper, an analytical mesh stiffness calculation model for non-uniformly distributed toothroot crack along tooth width is proposed based on previous studies. It enables a good prediction on the mesh stiffness for a spur gear pair with both incipient and larger tooth cracks. The results of this concluded that indicate that both the mesh stiffness and the dynamic response results show that the proposed analytical model is an alternative method for mesh stiffness calculation of cracked spur gear pairs with a good accuracy for both small and large cracks.**[3]** Carried out the research on the finite element analysis of contact fatigue and bending fatigue ofa theoretical assembling straight bevel gear pair. In this work propose a 3D FE model of assembling straight bevel gear pair to analyse the contact fatigue on the tooth surface and the bending fatigue in the tooth root. Based on the cumulative fatigue criterion and the stress–life equation, the key meshing states of the gear pair were investigated for the contact fatigue and the bending fatigue. The results of the study concluded that the fatigue failure of the driving pinion is the main fatigue failure for the straight bevel gear pair and the bending fatigue failure is the main fatigue failure for the driving pinion.**[4]**.carried out the research work on the analysis of bending fatigue in gears. In this research work a computational model for the determination of service life with regard to bending fatigue in a gear tooth root is presented. The results of the concluded that The Paris equation model is used to determine the service life of a real spur gear made from through-hardened steel 42CrMo4**[5]**presented the work on the numerical modeling of crack growth in a gear tooth root. In that computational model for determination of crack growth in a gear tooth root is presented. Twoloading conditions are taken into account for normal pulsating force acting at the highest point of thesingle tooth contact and the moving load along the tooth flank. The results of the study concluded that numerical analysis show that the prediction of crack propagation live and crack path in a gear tooth root are significantly different for both loading conditionsconsidered.**[6]**Presented research work on the simulation of crack propagation in spur gear tooth for different parameter and its influence on mesh stiffness. In that a cumulative reduction index (CRI) which uses a variable crack intersection angle to study the effect of different gear parameters on total time-varying mesh stiffness is studied. The results of the concluded that the proposed method is able to reflect the effect of differentgear parameters with increased deterioration level on total gear mesh stiffness-values.**[7]**presented the research work on the effects of spur gear tooth spatial crack propagation on gear mesh stiffness. In this research work influence of crack propagation on the time-varying Gear Mesh Stiffness (GMS) and also the Load Sharing Ratio (LSR) is presented. In order to quantitatively define the spatial crack propagation scenario, the involutes spur gear tooth geometry cut with a typical double rounded rack is first determined using two parametric equations. The results of the study conclude that for the dynamic simulation of gear transmission behavior, and consequently helpful for the monitoring of gearbox working condition and detection of early crack damage that may exist in gear sets

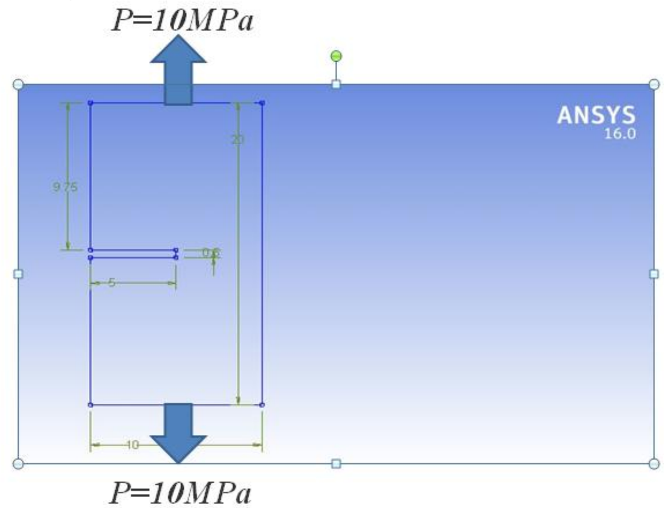
3 METHODOLOGY

The crack growth rate is analysis by Ansys followed by SEN specimen. Study the failure of gear theoretical and by taking the SEN specimen in aAnsys 16 as per standard parameter. By providing the crack thickness of 0.5mm of crack on gear tooth root and by Appling 10Mpa load then start crack is generated, Hence by providing proper mesh around crack the result is generated, Hence the graph of crack growth (da) v/s number of cycles ΔN is evaluated.

4. FINITE ELEMENT ANALYSIS XFEM USING SOFTWARE

MECHANICAL APDL 17.2

The following Mode I fatigue crack growth simulation using the XFEM based method. Fatigue crack growth calculations apply Paris' Law. The analysis uses a SEN specimen with a crack length (a) to width (W) ratio, a/ W = 0.5



(AllDimensions of SEN Specimen in mm)

Fig.SEN Specimen

The dimension of SEN Specimen:

Width =W=10.0 mm

Height =H=20.0 mm

Initial Crack Length =a=5 mm

Pressure applied on the plate = P=10.0 Mpa.

The material of specimen: Structural steel.

Young's Modulus, E=2 x10^5Mpa

Poisson's Ratio: μ=0.3

Paris Law Constant: $C = 3\text{x}10^{-13} \frac{\frac{mm}{cycles}}{MPa*\sqrt{mm}}$

m=3.0

Extended Finite Element Method (EFEM) analysis is use in the Mechanical APDL 17.2 Software

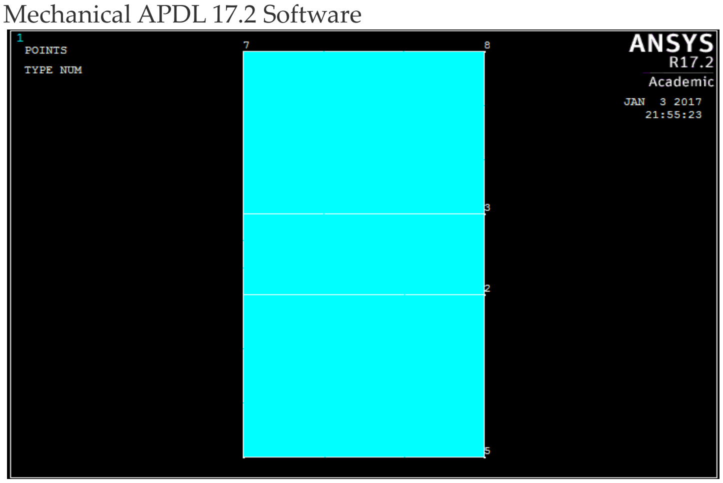


Fig.Finite Element Area of Specimen

The four node solid element eight node182 (PLANE 182element) is used to model the specimen. A fine mesh is use in the region near the crack surface:

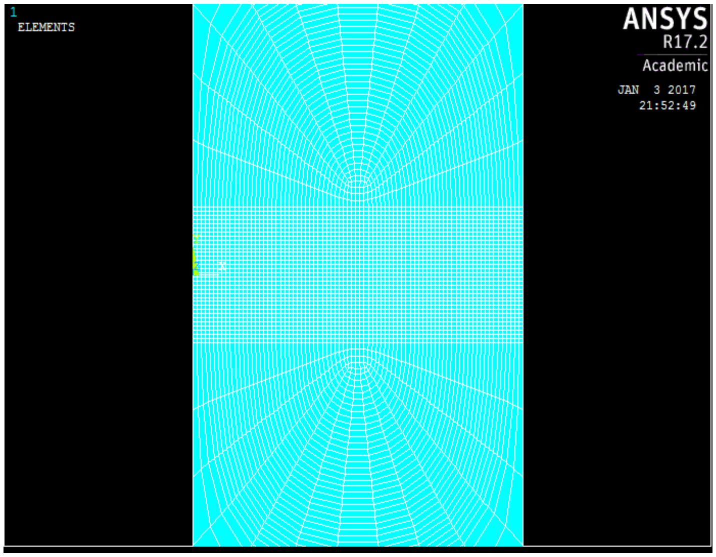


Fig: Finite Element Mesh for the SEN Specimen

5. RESULTAND DISCUSSION

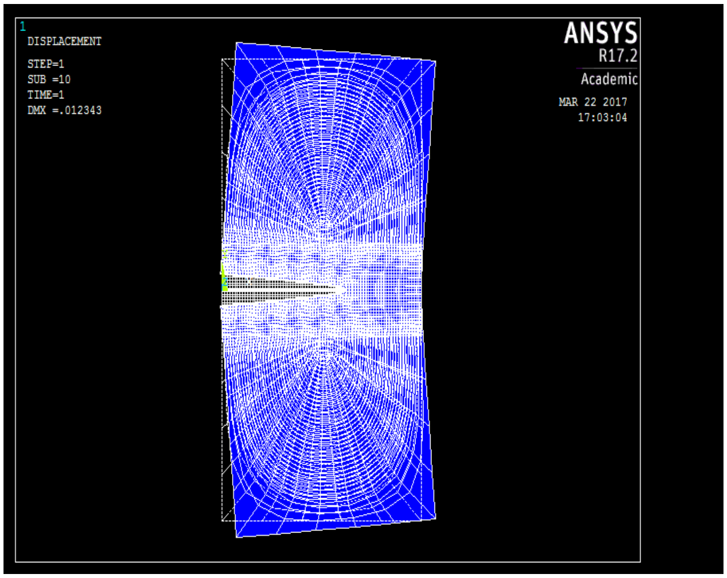


Fig: Final Displacement 0.012343 after Crack Growth

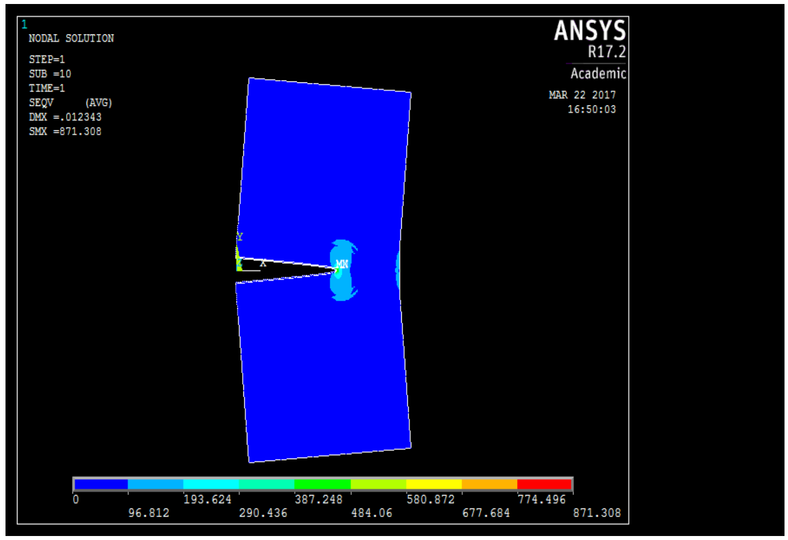


Fig: Equivalent Stress 871.308 Mpa at the End of the Analysis

In the fatigue crack growth LC method, the crack increment is fixe a priori (equal to the crack length in the element ahead of the current crack tip), and the incremental number of cycles is calculate for each substep.

The following figure shows the predicted number of cycles (MAPDL) versus the crack extension, as well as the theoretical results.

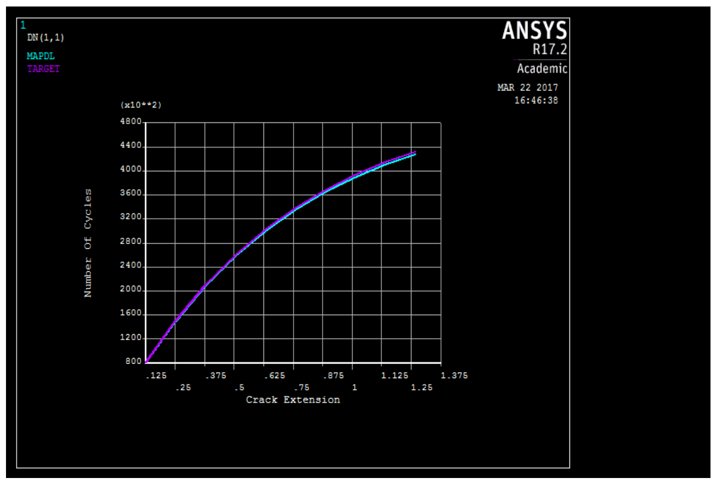


Fig: Variation of the Number of Cycles with Crack Extension

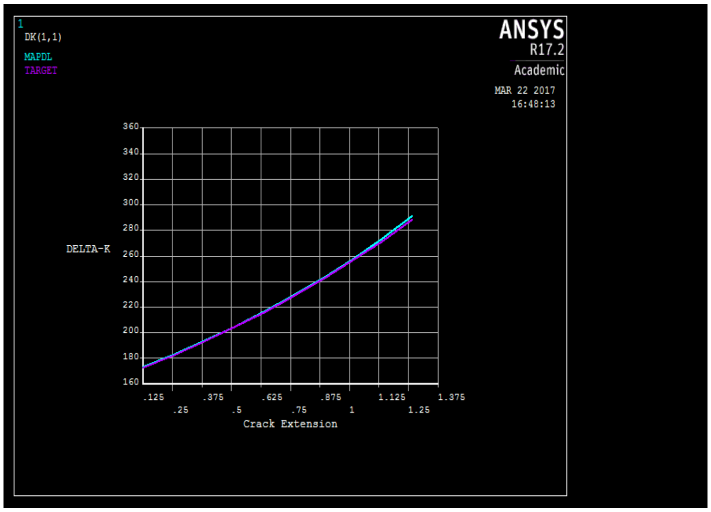
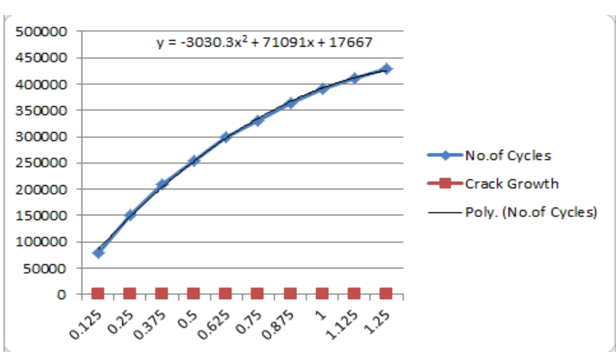


Fig: Variation DELTA-K of with Crack Extension

Table: FATIGUE CRACK GROWTH DATA

da	dN
0.125	80000
0.25	150000
0.375	210000
0.5	255000
0.625	300000
0.75	330000
0.875	365000
1	390000
1.125	410000
1.25	430000

From Table, We Plot Graph



6. Service Life Estimation (N_f)

With the help of above equation use this and we will get the residual life
Where,
N_f =service life or number of cycles.
From graph we got values
Final length of crack (af) =8mm.
Initial length of crack (ai) =5mm.
Stress Ratio =0.i.e Min Stress =0.
Max Stress =871.308 MPa

$$-3030.3(x)^2 + 71091(x) + 17667$$

Put.
$\mathbf{x = 3mm}$Inabove equation,

$$-3030.2(3)^2 + 71091(3) + 17667$$

$$= 203667.3\ cycles$$

We get, Service Life of Gear Tooth

Service Life of Gear Tooth=**203667.3** cycles.

7. Conclusion

It was observe that Von Mises stress after crack growth was 871.305 Mpa and Maximum deformation 0.012343 mm.

The response (graphs) of No. of Cycles v/s Crack extension and Deta K v/s Crack extension were got from simulation in Mechanical APDL.

The fatigue crack analysis in SEN Specimen is simulated to determine fatigue crack growth rate. The initial crack on spur gear and test specimen is considered same as 5mm length, and 0.5 mm cracked width and 8mm Final crack length and tested under pressure load of 10Mpa to evaluate the service life of specimen (or gear) **is** $N_f = \mathbf{203667.3}$cycles**.**

It is concluding that up to **203667.3** cycles the specimen sustains without failure.

8. Acknowledgment

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