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Tooth-Bending Effects in Spur Gear Tooth Influence on Load sharing and Stresses using Finite Element Method

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ABSTRACT

This paper describes the problem of determining crack initiation location and its influence on crack propagation in a spur gear tooth for different pressure angle. The crack progresses due to repeated cyclical loading at the zone of high stresses, by which there are several outcomes, which tends to generate crack and allow its propagation by smaller overlap ratio and a lower mesh stiffness that depends on the design which can be avoided by proper procedure in analysis. The designing of such gears using standard procedures yields only conservative results because of several assumptions made in the estimation of actual tooth load at the point of contact. Through an approach based on the load-sharing ratio (LSR), that calculates the tooth load, by which the mesh stiffness differs at different contact points along the path of contact, it significantly affects the LSR between the simultaneously meshed contact pairs. The present research work concentrates on the load sharing behavior of spur gear. The LSR is determined by the equivalent stiffness of each pair at any instant of contact is determined using the individual tooth stiffness of that pair in contact. The strain energy difference is validated by finite element analysis under proper LSR for a spur gear of different pressure angle. This study explores the effect of crack depth on the load sharing behavior and crack propagation path study based on the load sharing ratio has also been evaluated in this study.

1. INTRODUCTION

Gears are machine elements used to transmit rotary motion between two shafts, normally with a constant ratio. The pinion is the smallest gear and the larger gear is called the gear wheel. A rack is a rectangular prism with gear teeth machined along one side- it is in effect a gear wheel with an infinite pitch circle diameter. In practice the action of gears in transmitting motion is a cam action each pair of mating teeth acting as cams. Gear design has evolved to such a level that throughout the motion of each contacting pair of teeth the velocity ratio of the gears is maintained fixed and the velocity ratio is still fixed as each subsequent pair of teeth come into contact. When the teeth action is such that the driving tooth moving at constant angular velocity produces a proportional constant velocity of the driven tooth the action is termed a conjugate action.

2.0. GEAR GEOMETRICAL MODELING

The spur gear geometrical model is developed in finite element software package ANSYS through APDL (ANSYS Parametric Design Language) program using analytical equations given by Buckingham (1988) [3]. This model was developed for various pressure angle spur gear drives. These pressure angles are 14.5, 20, and 22. The gear specifications considered for analysis in this work are given in Tables.

3.1 PRESSURE ANGLE 14.5

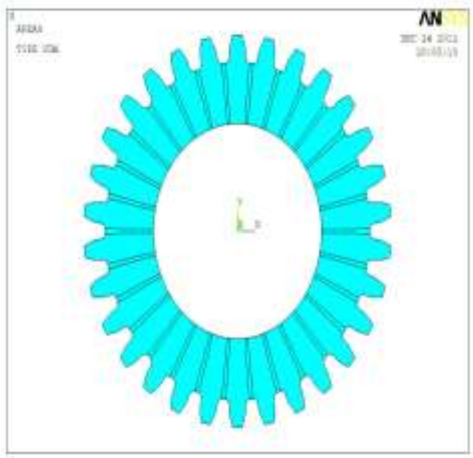

Figure-3.1

Module (m)	3
Number of teeth (Z)	20
Pressure Angle	14.5
Gear ratio (i)	1
Addendum	1*m
Dedendum	1.25*m
PCD	Z*m
Rim thickness	1*m & 5*m
Material	C45 Steel
Poisson Ratio	0.3
Young's Modulus	2.01e5 N/mm2

Table 2.1 Properties of Gear

2.2 PRESSURE ANGLE 20

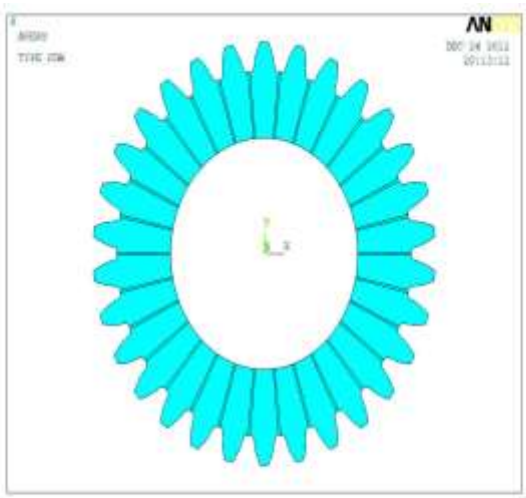

Figure-2.2

Module (m)	3
Number of teeth (Z)	20

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Pressure Angle	20
Gear ratio (i)	1
Addendum	1*m
Dedendum	1.25*m
PCD	Z*m
Rim thickness	1*m & 5*m
Material	C45 Steel
Poisson Ratio	0.3
Young's Modulus	2.01e5 N/mm2

Table 2.2 Properties of Gear

2.3 PRESSURE ANGLE 22

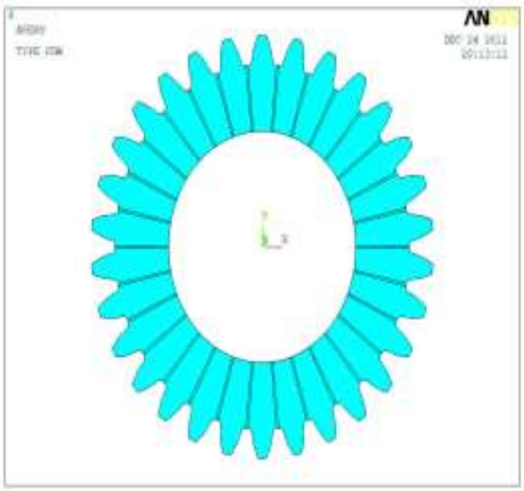

Figure-2.3

Module (m)	3
Number of teeth (Z)	20
Pressure Angle	22
Gear ratio (i)	1
Addendum	1*m
Dedendum	1.25*m
PCD	Z*m
Rim thickness	1*m & 5*m
Material	C45 Steel
Poisson Ratio	0.3
Young's Modulus	2.01e5 N/mm2

Table 2.3 Properties of Gear

3.0 ANSYS ANALYSIS APPROACH

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There are three main steps in our typical ANSYS analysis

3.1 MODEL GENERATION

- Simplifications, Idealizations.
- Define materials/material properties.
- Generate finite element model (mesh).

3.2SOLUTION

- Specify boundary conditions.
- Obtain the solution.

3.3 REVIEW RESULTS

- Plot/list results.
- Check for validity

3.4 BOUNDARY CONDITIONS

- There are two boundary conditions applied here
- The structural displacements are arrested in all degrees of freedom at the bottom of the gear model

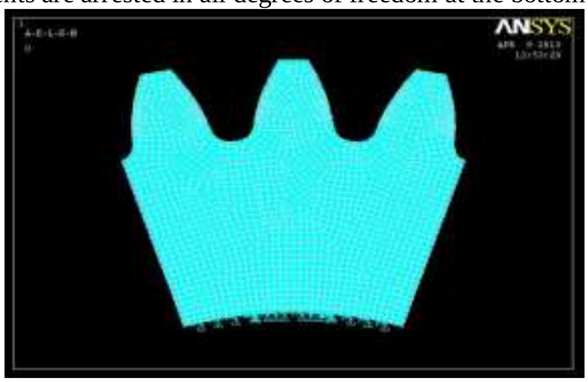

Figure-3.1 Displacements are arrested inDOF

1. The displacements are arrested in y degree of freedom at the sides of the gear model.

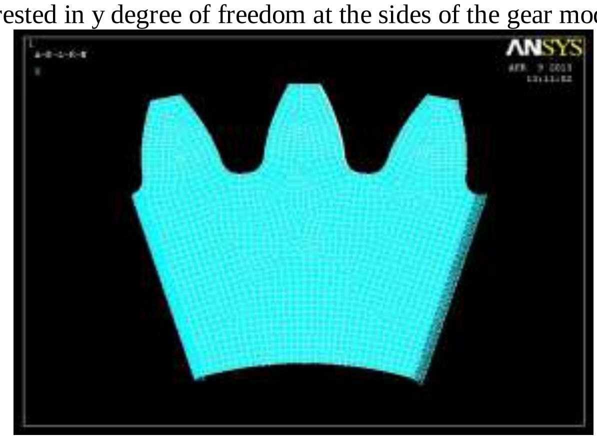

Figure-3.2 Displacements are arrested in y DOF

3.5 LOAD CONDITION

The load applied on the selected key point is point load $F_x$and F_y. The actual load is applied with appropriate values from load calculation. The main goal of a finite element analysis is to examine how a structure or component responds to certain loading conditions. Specifying the proper loading conditions is, therefore, a key step in the analysis. We can apply loads on the model in a variety of ways in the ANSYS program. Also, with the help of load step options, we can control how the loads are actually used during solution. A force is a concentrated load applied.

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Figure-3.3 Load applied on the selected key point $F_x$and F_y1.

Figure-3.4 Load applied on the selected key point $F_x$and F_y2.

3.6 SOLUTION

The gear model with all the constrains with the specified load conditions are solved in ANSYS and the results are obtained. In the solution phase of the analysis, the computer takes over and solves the simultaneous equations that the finite element method generates. The results of the solution are:

- Nodal degree-of-freedom values, which form the primary solution
- Derived values, which form the element solution

The element solution is usually calculated at the elements' integration points. The ANSYS program writes the results to the database as well as to the results file (Jobname.RST, RTH, RMG, or .RFL). Several methods of solving the simultaneous equations are available in the ANSYS program: frontal solution, sparse direct solution, Jacobi Conjugate Gradient (JCG) solution, Incomplete Cholesky Conjugate Gradient (ICCG) solution, Preconditioned Conjugate Gradient (PCG) solution, and an automatic iterative solver option (ITER).

3.7 ANSYS GENERAL POSTPROCESSOR

In this processor, the results at a specific time (if the analysis type istransient) over the entire or a portion of the model are reviewed. Thisincludes the plotting of contours, vector displays, deformed shapes, andlistings of the results in tabular format.

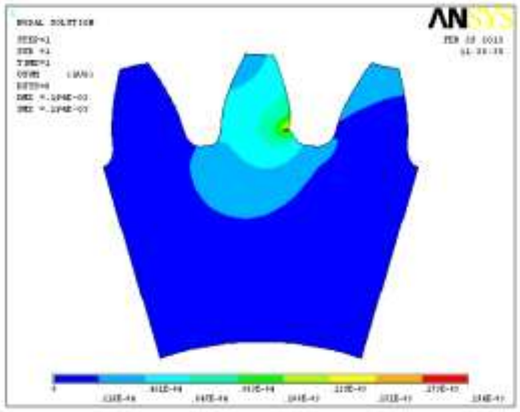

Figure –3.5 Solution of displacement vector sum in spur gear with PA 20 at key point 210

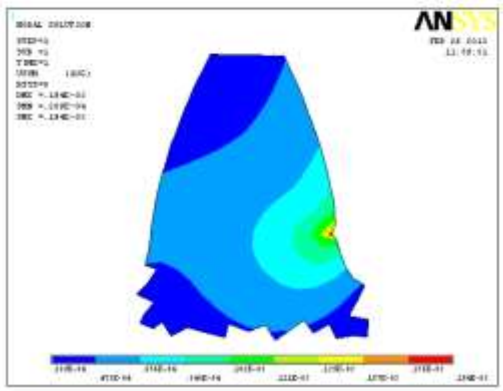

Figure –3.6 Solution of displacement vector sum in spur gear with PA 20 at key point 210

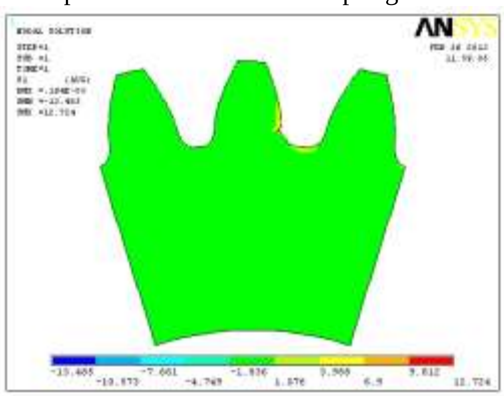

Figure –3.7 Solution of stress-1st principal stress in spur gear with PA 20 at key point 210

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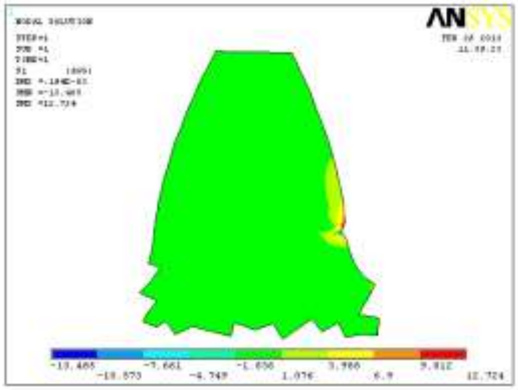

Figure –3.8 Solution of stress-1st principal stress in spur gear with PA 20 at key point 210 (Element view)

The loads are applied along the involute profile in 25 node points. It's clear that the key points are created separately for both the double contact and the single contact. Where the first and the last10 key points are of double contact and the intermediate 5 key points are single contact. Hence the results for different pressure angled spur gear are obtained.

4.0 VALIDATION AND COMPARISION OF STRESS FOR AGMA, LEWIS & FEM METHOD

In this chapter we deals with the Comparison of Stress for AGMA method, LEWIS & FEM Method for 20^0 pressure angle. By using these methods the stress values are obtained as given below:

Key points	Stress for FEM Method in ($^N/_{mm^2}$)	Stress for AGMA Method in ($^N/_{mm^2}$)	Stress for LEWIS Equation in ($^N/_{mm^2}$)
210	8.781	12.685492	9.93838
226	10	12.72273	9.967554
245	10.429	12.770086	10.00465
264	10.495	12.817588	10.04187
284	10.787	12.867696	10.08113
305	10.923	12.920375	10.1224
327	11.063	12.975585	10.16565
349	11.31	13.030779	10.20889
369	11.647	13.080909	10.24817
391	12.03	13.135972	10.29131

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422	12.337	13.190207	10.3338
453	12.724	13.246114	10.3776
482	12.977	13.298273	10.41846
514	13.257	13.35565	10.46341
544	13.28	13.409253	10.50541
572	14.574	13.459108	10.54447
589	14.951	13.52543	10.59642
604	15.255	13.587298	10.64489
619	17.673	13.64885	10.69312
634	18.425	13.710078	10.74109
650	19.295	13.775008	10.79196
665	19.387	13.835519	10.83936
678	20.168	13.887667	10.88022
710	20.499	14.014841	10.97985
753	20.527	14.182948	11.11155

In the above table is in the form of stress values of spur gear by FEM Method stress values are tabulated, and then the stress values in the spur gear of AGMA Method values and LEWIS Equation method are also tabulated. These values are compared by with use of graphical and calculations as given below. The average stress value of spur gear by FEM Method is 14.7776 and then average value of AGMA Method as 13.325338 and LEWIS Equation as 12.43966 then comparison of these values in the graph.

Compare to FEM and AGMA Method we have 5.5% of error and FEM with Lewis equation Method we have 11% error.

6.0 RESULTS AND DISCUSION

In spite of the number of investigations devoted to gear research and analysis there still remains to be developed, a general numerical approach capable of predicting the effect of stress, deflection, stiffness, and load sharing ratio for different pressure angles like 14.5, 20 and 22. The objectives of this study are to use a numerical approach to develop stress based on the behavior of the pressure angle of the spur gears in mesh; this is to help to predict the effect of gear tooth stresses.

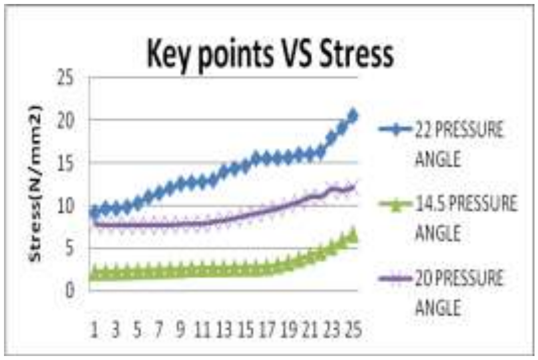
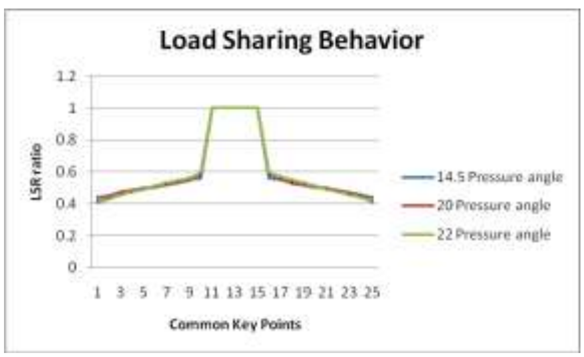


Figure-6.1 common key points vs stress

Hence a model of spur gear of different pressure angles like 14.5,20 and 22 was developed. And we also determined with appropriate models of contact elements, to calculate bending stresses for the spur gear of pressure angle 20^0 using ANSYS and compared the results with the experimental results of the David G. Lewicki and Roberto Ballarini (1996) the investigation of effect of rim thickness on gear tooth crack propagation by Analytical and experimental methods.

During meshing, the total load is shared among the simultaneously meshed pairs. The LSR is the ratio of the load shared by one of the pair to the total normal load.

Figure-6.2 common key points vs LSR



Whereas in case of deflection the comparison for different pressure angles shows in an order of 20 , 14.5 and 22. And similarly for the stiffness the increase is in an order of 22, 14.5 and 20.

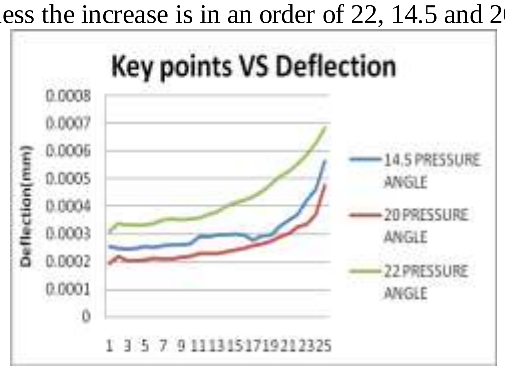


Figure-6.2 common key points vs deflection

And similarly a graph is drawn between the key point and stiffness the increase is in an order of 22, 14.5 and 20.The gear with pressure angle 22 is having the lowest stiffness and pressure angle 20 with the highest stiffness.

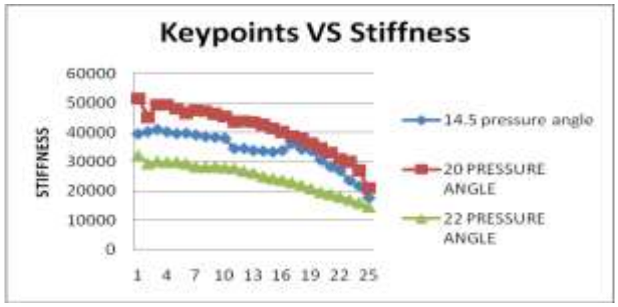


Figure-6.3 common key points vs stiffness

It explores the impact of different pressure angles on the life of a spur gear, the real comparison between all the above elements and how they vary depending on the pressure angles. When there is a increase in the pressure angle spur gear the stress that is induced on the gear also increases. For a gear to have a long life it is necessary to undergo a low stress, low deflection and higher stiffness value. This study finalizes that the spur gear with pressure angle 20 can be the optimized gear with low stress, low deflection and high stiffness. Hence the Impact of pressure angle on the spur gear drive and a study of stress, deflection, stiffness and load sharing ratio for different pressure angle of a spur gear are done.

7.0 CONCLUSION

Following were concluded from this study and the future work in this area are much recommended

- For any engineering failure analysis its always necessary to analyze the root cause elements like stress, deflection, stiffness and the load sharing ratio (LSR).
- Load sharing behaviour and stress analysis of 20 pressure angle spur gear teeth by using finite element method is validated with the experimental results of the David G. Lewicki and Roberto Ballarini (1996) investigation of effect of rim thickness on gear tooth crack propagation by Analytical and experimental methods.
- Two dimensional spur gear finite element models have been generated and analyzed in this work. The finite element method used to find out the deflection, stiffness, equivalent, stiffness, stress and load sharing ratio of the varying three pressure angle (14.5, 20, and 22) spur gear teeth.
- In deflection analysis, the deflection value of pressure angle 20 degree spur gear was very lower than the other two pressure angle spur gear teeth.

  This is the very first step to be ahead in finding the crack and its propagation which leads to prediction of various designs from failure.

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