Influence of Stress in Spur Gear at Root Fillet with Optimized Stress Relieving Feature of Different Shapes

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Abstract – Failure of gear causes breakdown of system which runs with help of gear. When gear is subjected to load, high stresses developed at the root of the teeth. Due to these high stresses, possibility of fatigue failure at the root of teeth of spur gear increases. There is higher chance of fatigue failure at these locations. So to avoid fatigue failure of the gear, the stresses should be minimized at maximum stress concentrated area. This work presents the possibilities of using the stress redistribution techniques by introducing the stress relieving features in the stressed zone to the advantage of reduction of root fillet stress in spur gear. This also ensures interchangeability of existing gear systems. In this work, combination of circular and elliptical stress relieving features are used and better results are obtained than using circular stress relieving features alone which are used by earlier researchers. A finite element model with a segment of three teeth is considered for analysis and stress relieving features of various sizes are introduced on gear teeth at various locations. Analysis revealed that, combination of elliptical and circular stress relieving features at specific, locations are beneficial than single circular, single elliptical, two circular or two elliptical stress reliving features.

Index Terms – Gear, Stress, FEA Software, Ansys

1. INTRODUCTION

1.1 Spur Gear

Spur gear is a cylindrical shaped gear in which the teeth are parallel to the axis. It is easy to manufacture and it is mostly used in transmitting power from one shaft to another shaft up to certain distance & it is also used to vary the speed & Torque. E.g. Watches, gearbox etc. The cost of replacement of spur gear is very high and also the system down time is one of the effect in which these gears are part of system. Failure of gear causes breakdown of system which runs with help of gear. E.g. automobile vehicle.

When gear is subjected to load, high stresses developed at the root of the teeth, Due to these high Stresses, possibility of fatigue failure at the root of teeth of spur gear increases. There is higher chance of fatigue failure at these locations. So to avoid fatigue failure of the gear, the stresses should be minimized at maximum stress concentrated area.

Design of spur gear can be improved by improving the quality of material, improving surface hardness by heat treatment, surface finishing methods. Apart from this stress also occurs during its actual working. Hence it is important to minimize the stresses. These stresses can be minimized by introducing stress relief features at stress zone.[13]

1.2 Problem Identification

Gears are used for a wide range of industrial applications. They have varied application starting from textile looms to aviation industries. They are the most common means of transmitting power. They change the rate of rotation of machinery shaft and also the axis of rotation. For high speed machinery, such as an automobile transmission, they are the optimal medium for low energy loss and high accuracy. Their function is to convert input provided by prime mover into an output with lower speed and corresponding higher torque. Toothed gears are used to transmit the power with high velocity ratio. During this phase, they encounter high stress at the point of contact.

A pair of teeth in action is generally subjected to two types of cyclic stresses: Bending stresses inducing bending fatigue Contact stress causing contact fatigue. Both these types of stresses may not attain their maximum values at the same point of contact. However, combined action of both of them is the reason of failure of gear tooth leading to fracture at the root of a tooth under bending fatigue and surface failure, due to contact fatigue.

The surface failures occurring mainly due to contact fatigue are pitting and scoring. It is a phenomenon in which small particles are removed from the surface of the tooth due to the high contact stresses that are present between mating teeth. Pitting is actually the fatigue failure of the tooth surface. Hardness is the primary property of the gear tooth that provides resistance to pitting. In other words, pitting is a surface fatigue failure due to many repetitions of high contact stress, which occurs on gear tooth surfaces when a pair of teeth is transmitting power. Gear teeth failure due to contact Fatigue is a common phenomenon observed. Even a slight reduction in the stress at root results in great increase in the fatigue life of a gear. [16]

1.3 Failure Modes of Gear Teeth

There are different failure modes of gear teeth some are given below:

- Tooth Breakage – Bending Fatigue
- Tooth Breakage – High Cycle Fatigue
- Tooth Breakage – Low Cycle Fatigue (Over Load)
- Tooth Breakage – Bending Fatigue

Bending stress can be minimized by introducing a stress relieving feature on the gear surface. Gears are mainly used to manipulate torque and speed of a motor or engine keeping the power output constant. In this work a spur gear has been tested virtually with ANSYS under a predefined loading and it has been investigated how bending stress changes at the fillet region of the spur gear with introduction of a stress reliving feature.

2. RELATED WORK

Deep Singh Vishwakarma et al, did a research on “Modeling and Reduction of Root Fillet Stress in Spur Gear Using Stress Relieving Feature” The main aim of their study is to relieve stress from the maximum value to as least as could be allowed. So the highest point of contact of teeth was selected as pressure application point which causes highest stress, then they selected Stress relieving feature having a shape of oval in the path of stress flow which helped to regulate stress flow by redistributing the lines of force.

Anand Kalani et al, did a study on “Increase in Fatigue Life of Spur Gear by Introducing Circular Stress Relieving Feature”, in their work they presented the possibilities of using the stress redistribution techniques by introducing the circular stress relieving features in the stressed zone to the advantage of reduction of root fillet stress in spur gear.

V. Rajaprabakaran et al, did a study on “Spur Gear Tooth Stress Analysis and Stress Reduction”, the main aim of their study was to relieve stress from the maximum value to as minimum as possible. So, they selected the highest point of contact of teeth as pressure application point which causes highest stress. Then Stress relieving feature having a shape of aero-fin was used in the path of stress flow which helped to regulate stress flow by redistributing the lines of force.

Dhavale A. S. et al, studied stress relief features at root of teeth of spur gear in the year 2013 and concluded that using two holes as a stress relieving feature gives more stress reduction

Vijaykumar Chalwa et al, did a research on, “Empirical relations to predict the probable percentage of reduction in root fillet stress in spur gear with circular stress relief feature” in their work Two categories of systematic analyses are carried out using finite element model of spur gear. In the first category of analyses emphasize is given to determine the maximum root fillet stress which they referred to determine the stress reduction factor. In second category they determined the effect of introducing geometric stress relief feature of circular shape of different size at strategic locations on a spur gear tooth

3. PORPOSED MODELLING

First work of Sumit Agrawal et al (Reference [10]) has been reproduced using FEA software ANSYS. In their work Sumit Agrawal et al analyzed a spur gear under a predefined loading using a Finite Element Analysis tool/software ANSYS and finally tested them physically. In the present work the analysis of a spur gear tooth of same dimension as taken by Sumit Agrawal et al [10] has been done using ANSYS to find out maximum bending stress at the fillet region of gear tooth. Modeling of these gears has been done using 3-D modeling software Pro-Engineer Wildfire 5.0 parametrically with the gear design parameters as mentioned in reference [10].

Parameters of Symmetric Gear

Parameters	Symmetric Toothed Gear
Number of Tooth (N)	32
Diametral Pitch (p)	0.21
Pressure Angle (Ø)	25°
Load	6950.334N

To generate symmetric gear in Pro/E here, only ‘Number of Teeth (N)’, ‘Diametral Pitch (P)’ and ‘Pressure angle (Ø)’ have been considered as input parameters and other parameters like:

Pitch Circle Diameter (DP) = Number of Teeth (N)/ Diametral Pitch (P)

Addendum (A) = 1/Diametral Pitch (P)

Dedendum (B) = 1.157/ Diametral Pitch (P)

Addendum Circle Dia (Da) = DP + 2*A

Dedendum Circle Dia or Root Circle Dia (Dr) = DP – 2*B

Base Circle Dia (Db) = DP * Cos (PHI)

Fillet radius (r) = 0.4 *A

Face Width (F) = 0.0625*DP

With the help of the involute curve a partial gear profile has been generated and then extruded to generate the partial 3-D model of gear teeth.

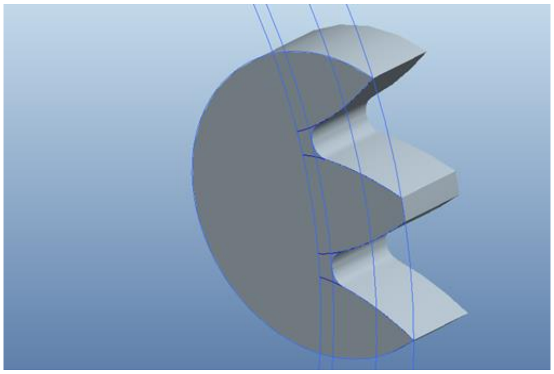


Fig 1: 3-D profile of partial gear teeth

4. STRUCTURAL ANALYSIS OF SPUR GEAR

The material has been used as an alloy steel of Grade-9310, 9310 is low alloy steel containing nickel, chromium and molybdenum. It has high core hardness and high fatigue strength. This alloy is best machined in the normalized and tempered state.

Mechanical properties of alloy steel Grade-9310:

Young's modulus (E)	2e5N/mm2
Density(ρ)	8e-6Kg/mm3
Poisson's ratio(ν)	0.3

Now, the partial 3-D model has been imported to the analysis software ANSYS for the purpose of simulation to find out Von-Misses stress at fillet region of the gear tooth under a loading condition as per R.L.Himte et. al [10]. Load applied to the gear tooth is 6950.334 N. In reality load is actually exerted on a line of contact passing through a point near pitch circle. But it is not possible as the meshing is unstructured and so a series of nodes cannot be available along a line near pitch circle. To avoid this problem load in the simulation is imposed at tip of the gear model with a modified pressure angle. The equation for calculation of modified pressure angle has been mentioned below to make the above consideration or assumption effective.

The equation is:

$$Ø_m = Ø - S_a/2r_a$$

Where-

$Ø_m$ is modified pressure angle.

Ø is actual pressure angle.

sa is tooth thickness at addendum circle.

ra is addendum circle radius.

From the above equation the modified pressure angle has been calculated as 24.05°.

After importing the 3-D gear model in ANSYS software it has been meshed in finite elements. To mesh a model there are many schemes available in ANSYS. But for any irregular body meshing is usually done by the default scheme already put in the software. Here the symmetric involute gear tooth has been meshed using the default scheme already present in the software. The load has been applied in two resolved directions. One in X-direction and other in Y-direction. As there are seven nodes on the edge of the tooth, the loads have further been divided by seven. After application of load the back rounded portion of the gear tooth has been fixed by imposing 'All Degree of Freedom' to zero. Figure below depicts the gear tooth with DOF imposed.

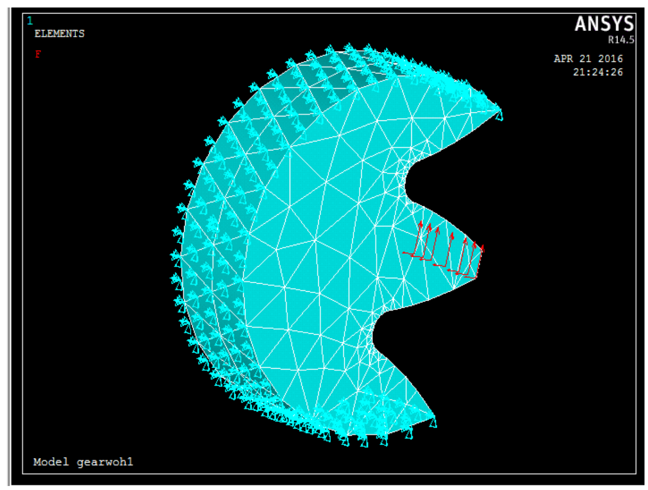


Fig 2: Meshed gear tooth with applied Degree of Freedom (DOF)

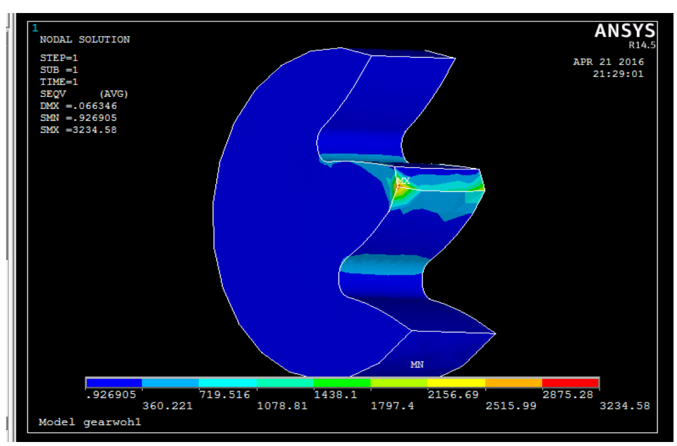


Fig 3: Von-Misses Stress Distribution of symmetric gear.

Maximum stress occurs at tooth tip but bending stress occurs at the fillet area.

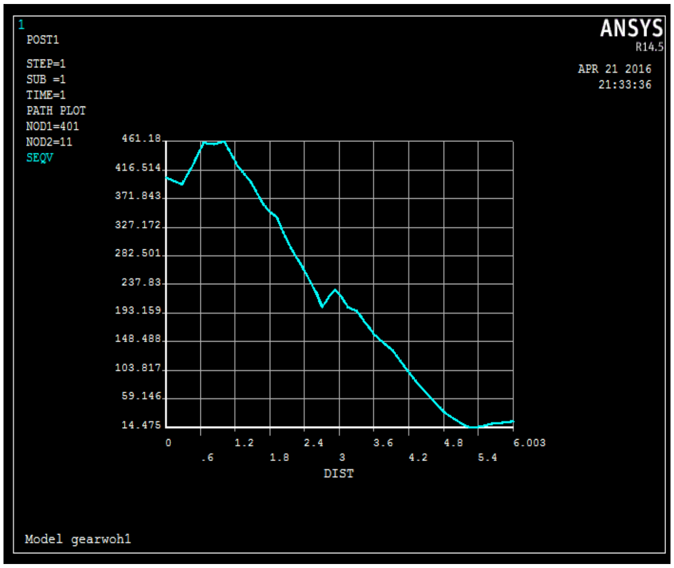


Fig 4: Graph of Von-Misses Stress Distribution at fillet area of symmetric gear

From the above figure it is clear that maximum bending stress is 461.18 N/mm2. This value of bending stress is very much in compliance with the value calculated by R.L. Himte et al [10] at their work. So, it can be said mathematical model of symmetric gear tooth with involute profile has been validated for further FEA analysis.

5. SYMMETRIC GEAR WITH STRESS RELIEVING FEATURES

Configurations of stress relieving feature used, for the various analyses are as follows:

- Circular stress reliving feature one at a time.
- Elliptical stress reliving feature one at a time.
- Circular stress reliving feature two at a time.
- Elliptical stress reliving feature two at a time.
- One circular and one elliptical stress relieving feature at a time.

Different number of trials has been given but better results were achieved by using configuration and position of holes which are described below for each case.

5.1 Using circular stress reliving feature one at a time

Radius of hole = 0.952381mm, radius of pitch circle = 68.571429mm and angular position of hole with respect to y-axis = 86.00°

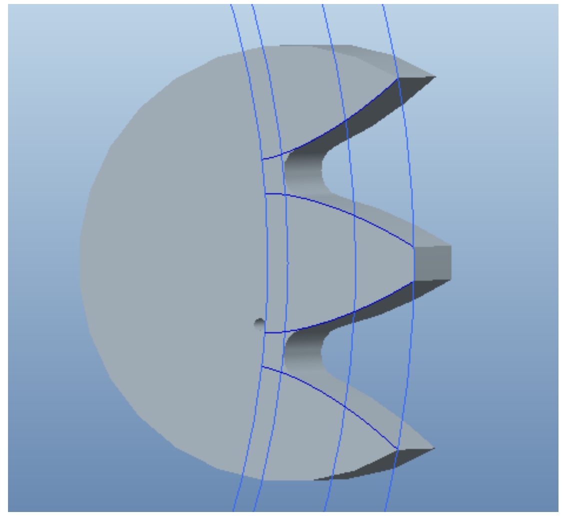


Fig 5: 3-D partial gear tooth profile with circular stress relieving feature

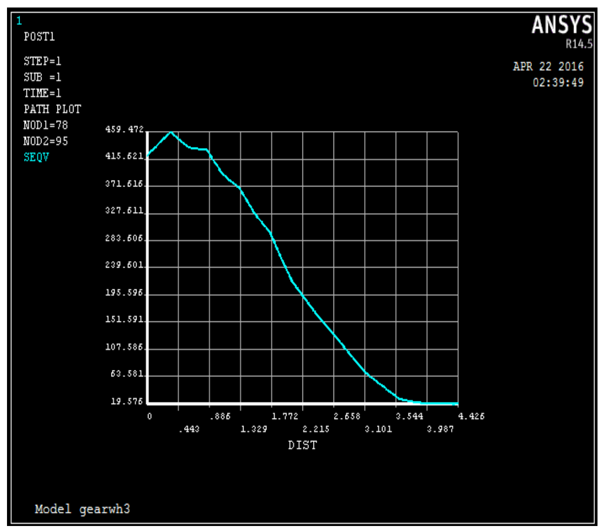


Fig 6: Graph of Von-Misses Stress Distribution at fillet area of symmetric gear with hole.

From the above figure it is clear maximum bending stress occurs at fillet of the symmetric gear is 459.472N/mm2, which is less than the maximum bending stress value calculated for symmetric gear tooth without any hole.

5.2 Using elliptical stress reliving feature one at a time

Major diameter of hole = 1.523810mm, minor diameter of hole = 0.761905mm, radius of pitch circle for hole = 67.809524mm, angle between the axis of hole-center and hole's major axis = 315° and angular position of hole with respect to y- axis = 85.5°,

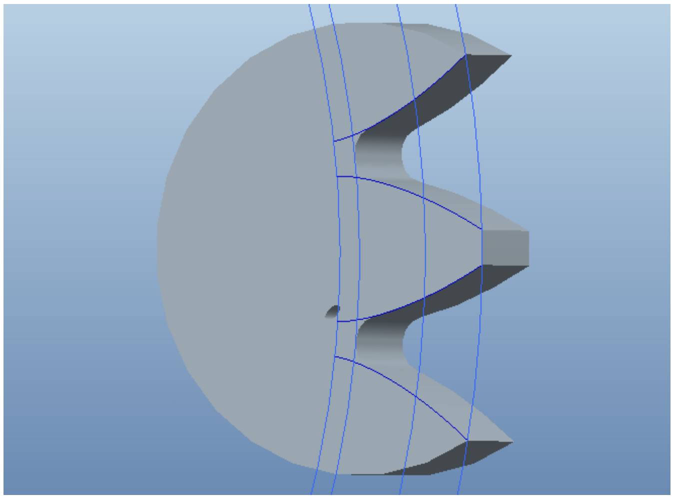


Fig 7: 3-D partial gear tooth profile with elliptical stress relieving feature

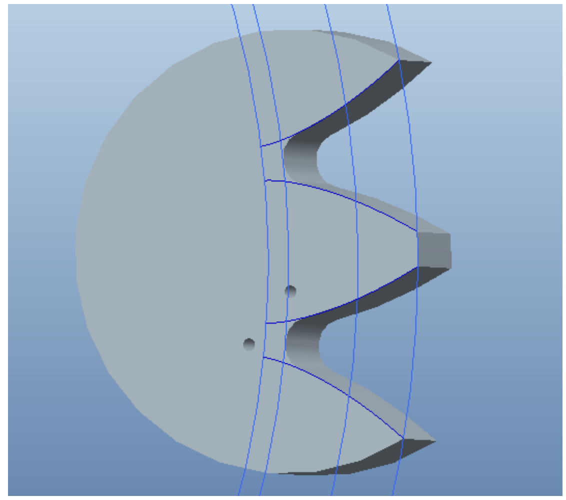


Fig 9: 3-D partial gear tooth profile with two circular stress relieving feature

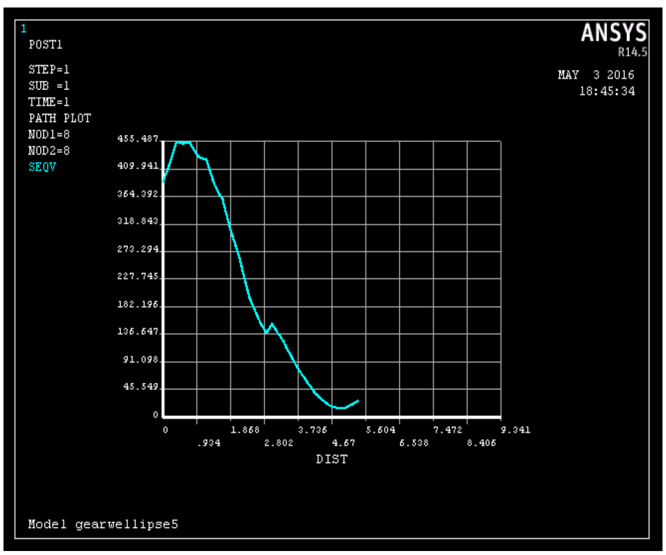


Fig 8: Graph of Von-Misses Stress Distribution at fillet area of symmetric gear with hole.

From the above figure it is clear maximum bending stress occurs at fillet of the symmetric gear is 455.487N/mm2, which is less than the maximum bending stress value calculated for symmetric gear tooth without any hole.

5.3 Using circular stress reliving feature two at a time

For circle-1, radius of hole = 0.952381mm, radius of pitch circle for hole = 67.809524mm, angular position of hole with respect to y- axis = 84.00° and

For circle-2, radius of hole = 0.952381mm, radius of pitch circle for hole = 70.857143mm, angular position of hole with respect to y-axis = 87.5°,

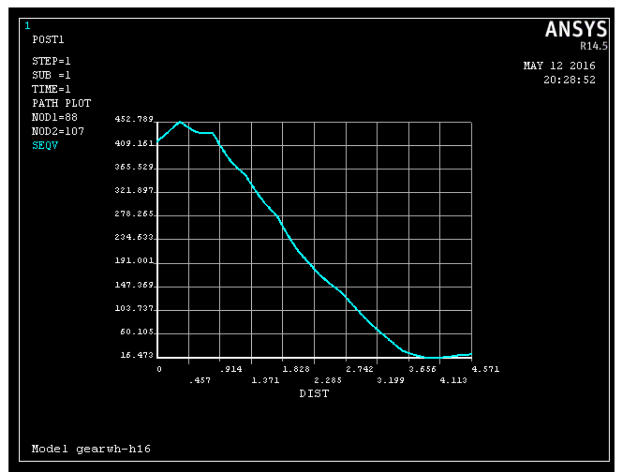


Fig 10: Graph of Von-Misses Stress Distribution at fillet area of symmetric gear with hole.

From the above figure it is clear maximum bending stress occurs at fillet of the symmetric gear is 452.789N/mm2, which is less than the maximum bending stress value calculated for symmetric gear tooth without any hole.

5.4 Using elliptical stress reliving feature two at a time

For ellipse-1, major diameter of hole = 1.523810mm, minor diameter of hole = 0.761905mm, radius of pitch circle for hole = 67.809524mm, angle between the axis of hole-center and hole's major axis = 45º, angular position of hole with respect to y- axis = 84.5° and

For ellipse-2, major diameter of hole = 1.523810mm, minor diameter of hole = 0.761905mm, radius of pitch circle for hole = 69.333333mm, angle between the axis of hole-center and hole's major axis = 45º, angular position of hole with respect to y- axis = 88.2°,

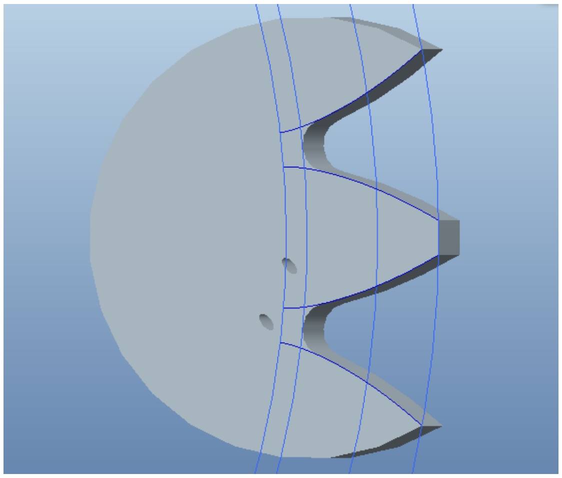


Fig 11: 3-D partial gear tooth profile with two elliptical stress relieving feature

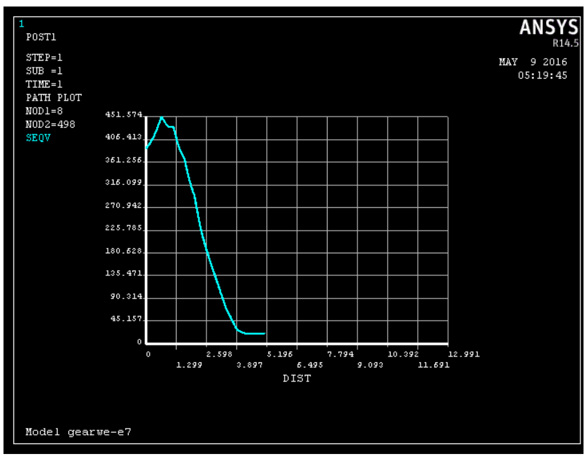


Fig 12: Graph of Von-Misses Stress Distribution at fillet area of symmetric gear with hole.

From the above figure it is clear maximum bending stress occurs at fillet of the symmetric gear is 451.574N/mm2, which is less than the maximum bending stress value calculated for symmetric gear tooth without any hole.

5.5 Using one circular and one elliptical stress relieving feature at a time

Elliptical hole: major diameter of hole = 1.523810mm, minor diameter of hole = 0.761905mm, radius of pitch circle for hole = 67.809524mm, angle between the axis of hole-center and hole's major axis = 45°, angular position of hole with respect to y- axis = 85.00° and

Circular hole: radius of hole = 0.609524mm and radius of pitch circle for hole = 69.333333mm, angular position of hole with respect to y-axis = 88°,

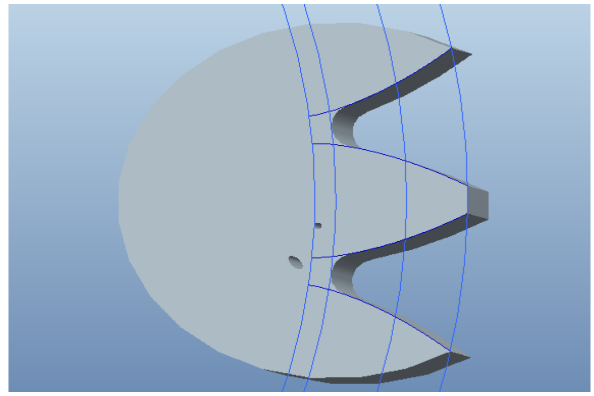


Fig 13: 3-D partial gear tooth profile with combination of circular & elliptical stress relieving feature

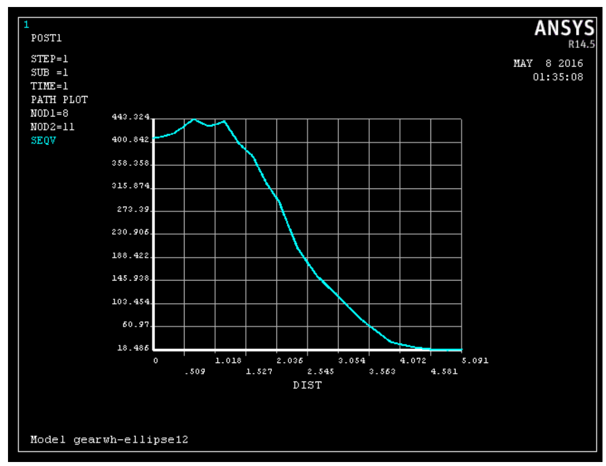
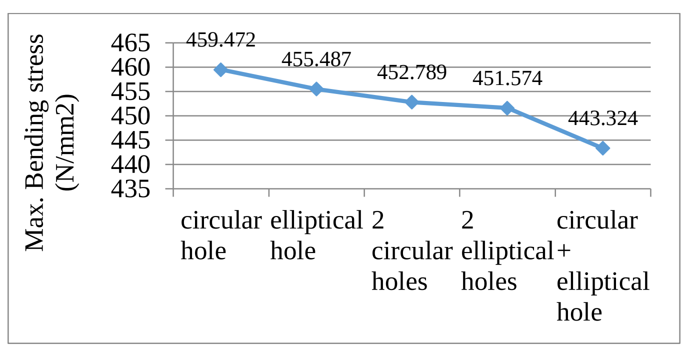


Fig 14: Graph of Von-Misses Stress Distribution at fillet area of symmetric gear with hole.

From the above figure it is clear maximum bending stress occurs at fillet of the symmetric gear is 443.324N/mm2, which is less than the maximum bending stress value calculated for symmetric gear tooth without any hole.

6. CONCLUSION



Graph 1: Comparison of max. bending stress obtained using different stress relieving features

Stress reductions by means of introducing stress reliving features with a combination of elliptical and circular holes are found to be better. The elliptical stress relief feature have better control over changing the stress redistribution pattern as it has more parameters (two axes and orientation) to redistribute the stress, over circular stress relief feature.

From the work it is clear that if a stress relieving feature, like a circular or elliptical hole, of suitable shape and dimensions can be put at correct position, bending stress of a symmetric gear can be reduced further.

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