

Research Paper

DESIGN AND ANALYSIS OF SHEAR STRESS REDUCTION IN AERO-FIN HOLED SPUR GEARS

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Gears are mechanical device which is used transmission purposes. They do several important jobs, mostly speed reduction in mechanical equipments. The main objective of this study is to analyse the stress in gear tooth and to reduce the stress in the gear tooth. An ansys analysis of spur gear is used in this paper. A Finite Element model with aero-fin shaped hole along the stress flow direction reveals that it gives better results..

Keywords: Spur gears, FEM, Stress analysis, Stress reduction.

INTRODUCTION

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: i) Bending stresses inducing bending fatigue ii) 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. When loads are applied to the bodies, their surfaces deform elastically near the point of contact. Stresses developed by Normal force in a photo-elastic model of gear tooth. The highest stresses exist at regions where the lines are bunched closest together. The highest stress occurs at two locations: A. At contact point where the force F acts B. At the fillet region near the base of the tooth.

The surface failures occurring mainly due to contact fatigue are pitting and scoring. It is a phenomenon in which small particles are

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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.

For many years, gear design has been improved by using improved material, hardening surfaces with heat treatment and carburization, and shot peening to improve surface finish etc. Few more efforts have been made to improve the durability and strength by altering the pressure angle, using the asymmetric teeth, altering the geometry of root fillet curve and so on. Some research work is also done 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 3 gear. This also ensures interchangeability of existing gear systems. The studies in which combination of circular and elliptical stress relieving features are used obtained better results than using circular stress relieving features alone which are used by earlier researchers. In this research work, an aero-fin shaped stress relieving feature is tried. A finite element model with a segment of three teeth is considered for analysis and a stress relieving feature of various sizes are introduced on gear teeth at various locations.

Purpose

Gearing is one of the most critical components in mechanical power transmission systems. The

transfer of power between gears takes place at the contact between the mating teeth. During operation, meshed gears teeth flanks are submitted to high contact pressures and due to the repeated stresses, damage on the teeth flanks, in addition to tooth breakage at the root of the tooth is one of the most frequent causes of gear failure. This fatigue failure of the tooth decides the reliability of the gear. However, by introducing stress relieving features to the gear, the points of stress concentration can be decreased which enhances life of gear. A study is done on spur gear with involute profile by adding stress relieving features of different shapes and best among them is proposed.

Hardware Used

Intel core i3 processor of 2.2GHz, 2GB of RAM.

Software Used

All the modelling is done in SolidWorks 13, Mesh generation, solving and post-processing are done in Ansys 14.

Literature Review

Investigators analyzing the gear tooth for stresses have done several studies:

A Manoj Hariharan (2006) conducted stress analysis on 8 different gears by determining the highest point of contact for all gears. Stress analysis for the load contact point travelling along the involute curve is done for gears. The point of contact where maximum stress occurs is determined for all eight test gears and the variation of this H (Highest point of Contact) diameter for contact ratio greater than one is studied. Then the gear ratio where it is maximum is taken for application of force for all studies. From the results, he compared the stresses on each gear with their respective highest point of

contacts and selected the weak gear among those for stress relief studies. He introduced circular holes as stress relieving features at different locations and also varied the diameters of holes. He concluded with an optimization study of drilling two circular holes, each on two mating teeth at the same location relative to each tooth, stress can be reduced.

M S Hebbel *et al.*, (2009) used elliptical and circular holes as a stress relieving feature. 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 relieving features.

Shanmugasundaram Sankar *et al.*, (2010) did a study using circular root fillet instead of the standard trochoidal root fillet. The result reveals that the circular root fillet design is particularly suitable for lesser number of teeth in pinion and where as the trochoidal root fillet gear is more opt for higher number of teeth.

Ashwini Joshi and Vijay Kumar Karma (2010) did a work which deals with the effect on gear strength with variation of root fillet design using FEA. Circular root fillet design is considered for analysis. The loading is done at the highest point of single tooth contact (HPSTC).

Fredette and Brown (1997) used holes drilled across the entire tooth as a function of size and location. The ultimate objective of this work was to find the overall effect of hole size and location on the critical stresses in the gear.

Sorin Cananau (2003) on an exact geometry design of the involute gear tooth, a set of profile gears is obtained in order to calculate the 2D contact. A stress analysis was performed for CAD profiles results using the finite element procedure.

The paper investigates the 2D analysis versus 3D analysis for stress in the root region of teeth. By this approach, is also investigated the influence of non-uniform load along contact line to the fillet stress.

Ali Raad Hassan (2009) did a research study in which Contact stress analysis between two spur gear teeth was considered in different contact positions, representing a pair of mating gears during rotation. A programme has been developed to plot a pair of teeth in contact. Each case was represented a sequence position of contact between these two teeth. The programme gives graphic results for the profiles of these teeth in each position and location of contact during rotation. Finite element models were made for these cases and stress analysis was done. The results were presented and finite element analysis results were compared with theoretical calculations, wherever available.

The idea of using holes to reduce stresses is not a new one. In 1990, Dippery (Ali Raad Hassan, 2009) experimented with the use of supplementary holes in a structure as a method of reducing the stress concentration that was already present. His result showed that stress concentration reductions are possible in a generic shape using holes as stress relief.

The researchers till now used circular and elliptical holes as stress relieving features with different sizes and at various positions which showed evidence that stress can be reduced interrupting the stress flow path from contact point to fillet.

This project is an extension of work done by A Manoj Hariharan. He has taken a weak profile gear from his studies and conducted stress analysis on it by inserting circular holes as stress

relieving features at different locations. The gear with all its dimensions is replicated and the highest point of contact is calculated in the similar way in the contemporary project. In this project, an aerodynamic fin shaped hole is used as a stress relieving feature which differs from circular holes used in the former one. It yielded better results comparatively but this aerodynamic shaped hole is limited to uni-directional gears only.

Spur Gear Geometry

Here we present the calculations for the gear we will use for our stress concentration reduction studies. Please note that this is the same gear geometry used by Hariharan (2006). As given in (Joseph Edward Shigley, 1986), the gear geometry calculations are as follows:

Considering the pressure angle (ϕ) = 20° Pitch circle Dia. (PCD) = module(m) x no. of teeth

Tooth thickness = $(\pi \times \text{module}) / 2$

Root fillet = 0.2 x module Addendum

Dia.(Da) = PCD + 2 x module Dedendum

Dia.(Dd) = PCD – 2.5 x m Base circle dia.

(Db) = PCD x cos ϕ

Parameters of Gear

Module (m) = 2 Pitch circle dia (d) = 50mm

No. of teeth (N) = 16

Tooth thickness (t) = 3.14mm

Root fillet = 0.628mm

Addendum dia (Da) = 54mm

Dedendum dia (Dd) = 45mm

Base circle dia (Db) = 46.984mm

Material used: Structural Steel

Properties of Steel

Young's modulus = 20000 Mpa

Poisson's ratio = 0.3

Gear Design Calculations

The Pitch Diameter (D) = 50

The Pitch Radius (R) = D/2 = 25

The Base Circle Diameter (DB) = D * COS (PA)
= 1.25 * COS (14.5 deg) = 46.984

The Base Circle Radius (RB) = DB/2 = 23.492

The Addendum (a) = 1/P = 1/6.28 = .15924

The Dedendum (d) = 1.157/P = 1.157/6.28 = .18424

Outside Diameter (DO) = D+2*a = 50.318

Outside Radius (RO) = 25.159

Root Diameter (DR) = D-2*d = 1.1054

Root Radius (RR) = 0.5527

For method [9] described below following calculations are also required:

1. Circumference of the Base circle, (CB) = Pi * (DB) = Pi * 46.984 = 147.6
2. 1/25th of the Base Circle Radius, (FCB) = .9396
3. Number of times that FCB can be divided into CB, (NCB) = 157.08
4. 360 degrees divided by NCB, (ACB) = 2.29
5. Gear Tooth Spacing (GT) = 360/T = 14.4 degrees

ELEMENT USED FOR MESHING

Structural Steel

Structural steel is steel construction material, a profile, formed with a specific shape or cross section and certain standards of chemical composition and mechanical properties. Structural steel shape, size, composition, strength,

storage, etc., is regulated in most industrialized countries.

Although the structure of the element is straightforward, it should not be used in the following situations:

1. Due to the full integration, the element will behave badly for isochoric material behavior, i.e. for high values of Poisson's coefficient or plastic behavior.
2. The element tends to be too stiff in bending, e.g. for slender beams or thin plates under bending.

GEOMETRY CREATION AND MESH GENERATION

The geometry is created using the solidworks software.

Finite Element Mesh Generation

A finite element mesh is a positioning of a given subset of the three-dimensional space by elementary geometrical elements of various shapes. The mesh generation is performed in the bottom-up flow i.e., lines are discretized first; the mesh of the lines is then used to mesh the surfaces; then the mesh of the surfaces is used to mesh the volumes. In this process, the mesh of an entity is only constrained by the mesh of its boundary. For example, in three dimensions, the triangles discretizing a surface will be forced to be faces of tetrahedra in the final 3D mesh only if the surface is part of the boundary of a volume. This automatically assures the conformity of the mesh. This size field can be uniform or specified by values associated with points in the geometry.

Figure 1: Extruded Spur Gear

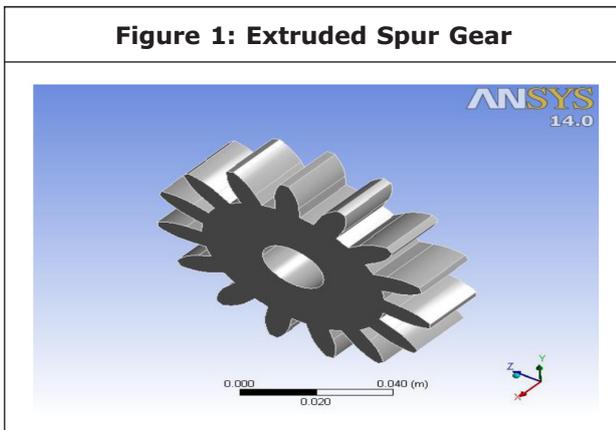


Figure 3: Meshing of Spur Gear with Aero-Hole

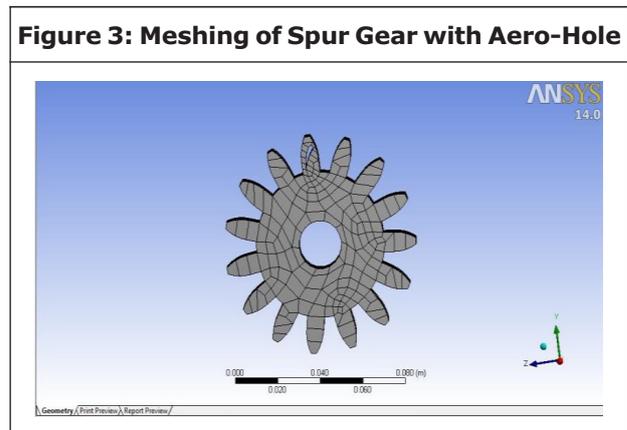
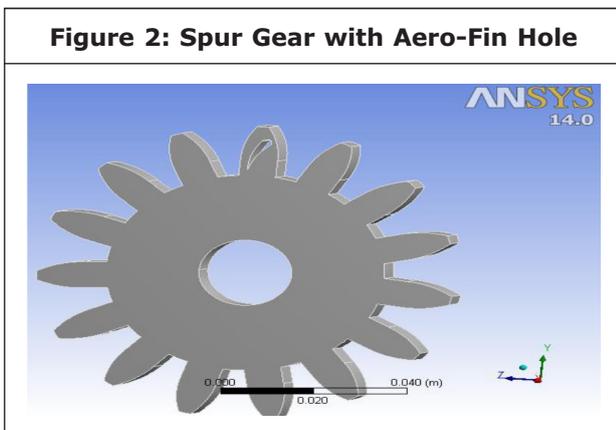


Figure 2: Spur Gear with Aero-Fin Hole



RESULTS AND DISCUSSION

Problem Definition

A gear having specifications of Module (M)=2, No. of teeth(N)=16 to study and experiment is chosen from our reference thesis (Manoj Hariharan, 2006). A load of 500N as given in thesis is applied at the highest point of contact of gear teeth. The stress at root fillet region is of the value 168Mpa which is much higher than the actual applied load. The stress relieving features

used in the gear till date are circular holes or the combination of circular and elliptical holes. Here we have tried an aerodynamic structured hole in the path of stress flow analogy and the results are analysed. Here a normal gear is first analysed and then a spur gear with aero-fin hole is analysed by applying a load of 500N.

Significance of Aero-Fin Hole

The shape of aero-fin is used to modify the stress flow into a smoother way, i.e., aero-fin hole helps in achieving the stress reduction the given spur gears. The aero-fin hole is make the stress flow in the spurs gears smoother than the gears without the aero-fin hole.

Results: Stresses in Analysed Gears

First the gear without hole is examined to determine the maximum stress at the fillet and then the aero-fin hole is introduced to gear. The analysis is done using the ANSYS14 software. The stresses and displacements are calculated and analyzed so that the maximum stress at the fillet is reduced which is the main aim of this project.

Stress in Normal Gear

The maximum stress at the fillet is 358.04 Mpa which much higher compared to the applied load on the gear.

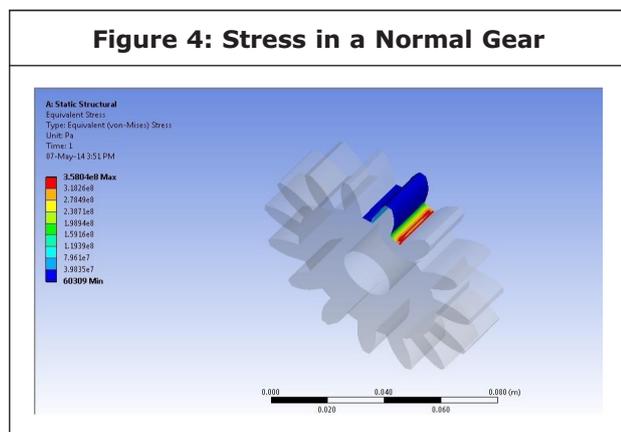


Figure 4: Stress in a Normal Gear

Stress in Gear (with Aero-Fin Hole)

The maximum stress at the fillet is 239.43 Mpa after the introduction of aero-fin hole.

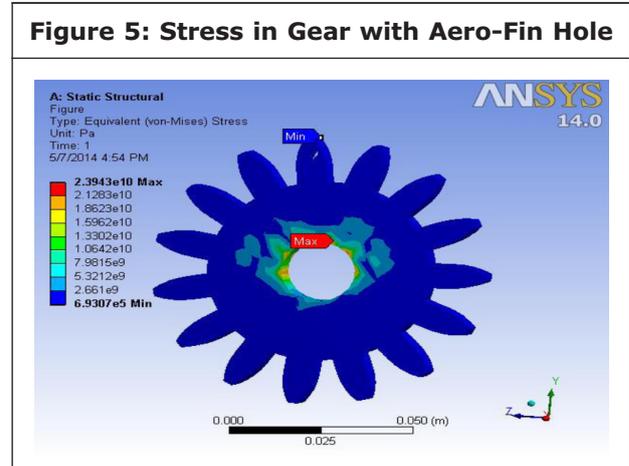


Figure 5: Stress in Gear with Aero-Fin Hole

GRAPHS

Stress in Normal Gear

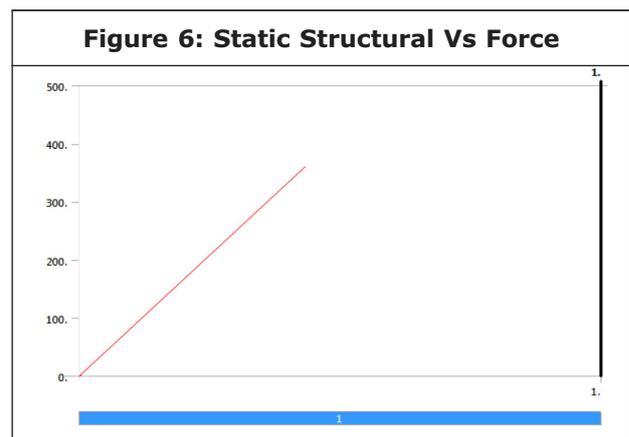


Figure 6: Static Structural Vs Force

Stress in Gear (with Aero-Fin Hole)

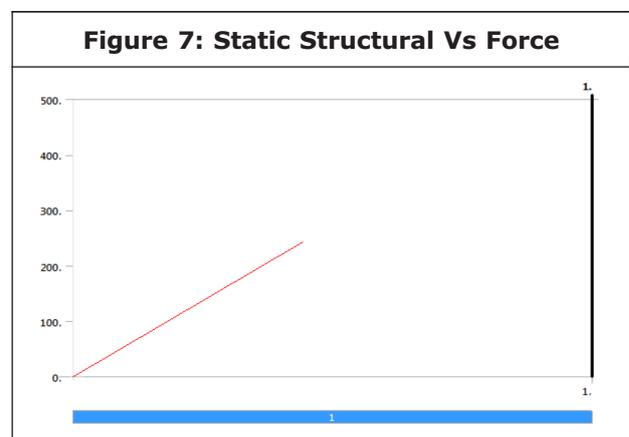


Figure 7: Static Structural Vs Force

From the above two graphs it can be concluded that as the aero-fin hole is introduced, stress induced in the gear decreased significantly due to the modulation of hole in the stress flow direction.

CONCLUSION

The main aim of this paper is to reduce the stress in the spur gear the tooth due to friction from as minimum as possible. So the highest point of contact of teeth is selected as the pressure application point which causes highest stress.

This study gives the better result when an aero-fin hole is introduced and reduces the stress in the gear teeth upto 66.87%.

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