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Analysis of Stress Reduction and Spur Gear Tooth Stress

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ABSTRACT

Gears are usually used for transmitting energy. They develop high strain awareness at the basis and the factor of touch. The repeated stressing on the fillets causes the fatigue failure of gear teeth. the principle goal of this have a look at is to add specific shaped holes to reduce strain awareness. A finite element version of Spur gear with a phase of three tooth is considered for analysis and strain concentration reducing holes of numerous sizes are added on tools teeth at diverse places. evaluation found out that aero-fin formed hole brought along the strain flow course yielded better results.

Keywords: Spur Gear Tooth Stress, Spur Gear, Fillet Radius, Finite Detail Approach, CalculiX Graphics, CalculiX, CCX, AutoCAD, ABAQUS, layout internet layout

I. INTRODUCTION

Gears are used for a wide range of industrial applications. They have varied utility beginning from fabric looms to aviation industries. They are the maximum not unusual way of transmitting energy. They trade the price of rotation of equipment shaft and also the axis of rotation. For excessive pace equipment, along with an car transmission, they may be the surest medium for low strength loss and excessive accuracy. Their feature is to convert input supplied by using top mover into an output with lower speed and corresponding higher torque. Toothed gears are used to transmit the electricity with high velocity ratio. Throughout this segment, they encounter high pressure on the factor of contact. a pair of enamel in motion is generally subjected to two forms 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:

1. At contact point where the force F acts
2. 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 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

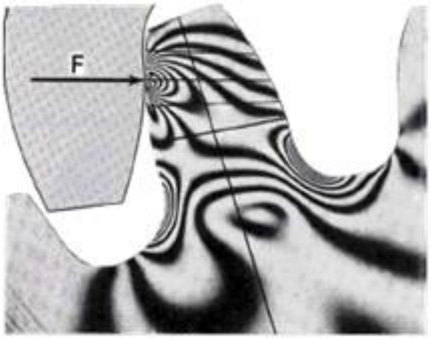


Figure 1

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 gear. This also ensures interchange ability 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 are 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.

II. METHODS AND MATERIAL

2.1 Gear Nomenclature:

Pitch surface: The surface of the imaginary rolling cylinder that replaces the toothed gear. Pitch circle: A normal section of the pitch surface.

Addendum circle: A circle bounding the ends of the teeth, in a normal section of the gear. Dedendum circle or Root circle: The circle bounding the spaces between the teeth, in a normal section of the gear. Fig 1 Involute Spur gear

Addendum: The radial distance between the pitch circle and the addendum circle. Dedendum: The radial distance between the pitch circle and the root circle.

Clearance: The difference between the Dedendum of one gear and the Addendum of the mating gear.

Face of a tooth: That part of the tooth surface lying outside the pitch surface. Flank of a tooth: The part of the tooth surface lying inside the pitch surface. Top land: The top surface of a gear tooth.

Bottom land: The bottom surface of the tooth space.

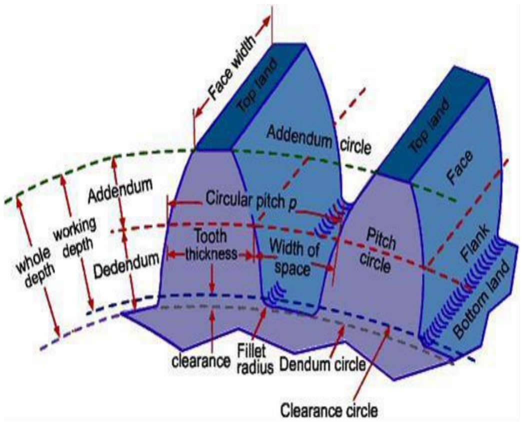


Figure 2

Circular thickness: The thickness of the tooth measured on the pitch circle. It is the length of an arc and not the length of a straight line.

Tooth space: The space between successive teeth.

Width of space: The distance between adjacent teeth measured on the pitch circle.

Backlash: The difference between the tooth thickness of one gear and the tooth space of the mating gear.

Circular pitch (P): The width of a tooth and a space, measured on the pitch circle. It is equal to the pitch circumference divided by the number of teeth.

Diametrical pitch (P): The number of teeth of a gear per unit pitch diameter. The diametric pitch is hence the number of teeth divided by the pitch diameter.

Module (M): Pitch diameter divided by number of teeth. The pitch diameter is usually specified in millimetres.

Fillet Radius: The small radius that connects the profile of a tooth to the root circle.

Base circle: An imaginary circle used in involute gearing to generate the involutes that form the tooth profiles.

Contact Ratio: The average number of gear tooth pairs in contact on a pair of meshing gears.

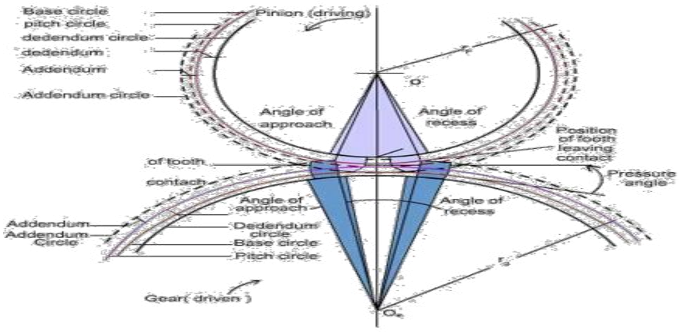


Figure 3. Meshing of Gear teeth

Pitch point: The point of tangency of the pitch circles of a pair of mating gears.Common tangent: The line tangent to the pitch circle at the pitch point.

Line of action: A line normal to a pair of mating tooth profiles at their point of contact. Path of contact: The path traced by the contact point of a pair of tooth profiles.

Pressure angle: The angle between the common normal at the point of tooth contact and the common tangent to the pitch circles. Pressure angle is also the angle between the line of action and the common tangent.

Crowning: Grinding of tooth edges to prevent edge loading is known as crowning.

Spur gear: Spur gears are the most common type of gears. They are used to transmit rotary motion between parallel shafts i.e., they are usually cylindrical in shape, and the teeth are straight and parallel to the axis of rotation. Sometimes many spur gears are used at once to create very large gear reductions. Spur gears are used in many devices but not in cars as they produce large noises.

Figure 4. Spur Gear

2.2 Conjugate action:

Mating tools teeth towards every different to produce rotary motion are much like cams. When the enamel profiles are designed in order to produce a regular angular-velocity ratio in the course of meshing, they may be stated to have conjugate motion. a geometrical relationship can be derived for the form of enamel profiles to offer conjugate motion that's summarized as law of Gearing as follows:“A not unusual normal to the tooth profiles at their point of contact need to, in all positions of the contacting tooth, bypass via a set point on the road-of-centres known as the pitch point." Any two curves or profiles attractive every other and fulfilling the law of gearing are conjugate curves. The angular-speed ratio between the 2 hands is inversely proportional to their radii to the point P. Circles drawn via factor P from every centre are called pitch circles, and the radius of each circle is referred to as the pitch radius. Factor P is called the pitch factor

2.3 Tooth profile

The cycloid AL gear profile is a form of toothed gear used in mechanical clocks. The gear tooth profile is based on the epicycloids and hypocycloid curves, which are the curves generated by a circle rolling around the outside and inside of another circle, respectively. An advantage of the cycloid AL teeth over the involute one is that wear of Cycloid AL tooth is not as fast as with involute tooth. For this reason, gears transmitting very large amount of power are sometimes cut with cycloid AL teeth.

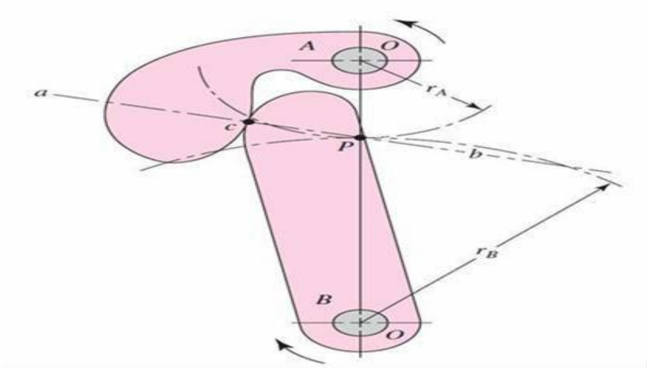


Figure 4. Conjugate action

Since the cycloid AL teeth have wider flanks, therefore the cyclical gears are stronger than the involute gears, for the same pitch. These are preferred for cast teeth.

In cycloid AL gears, the contact takes place between a convex flank and concave surface, where as in involute gears, the convex surface are in contact. This condition results in less wear in cycloid AL wear and however the difference in wear is negligible.

The interference in cycloid AL gears does not occur at all. Though there advantages of cycloid AL gears they are outweighed by the greater simplicity and flexibility of the involute gears.

Involute:

The involute gear profile is the most normally used system for gearing. In an involute gear, the profiles of the teeth are involutes of a circle. The involute of a circle is the spiralling curve traced by the end of an imaginary taut string unwinding itself from that stationary circle called the base circle. In involute gear design, contact between a pair of teeth occurs at a single instantaneous point. Rotation of the gears causes the location of this contact point to move across the respective tooth surfaces.

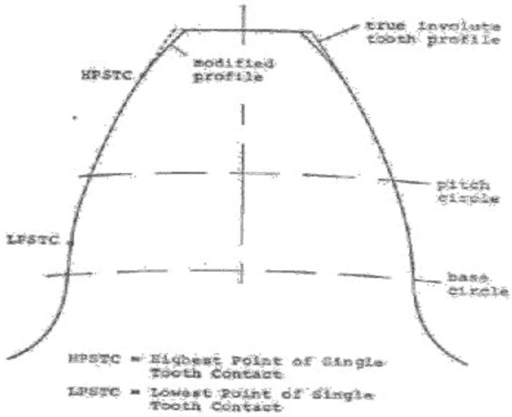


Figure 5. Involute profile of gear tooth

Involute teeth are very easy to manufacture and the actual distance between the centres may deviate slightly from the theoretical distance without affecting the velocity ratio or general performance. Because of this distinct advantage, gears with involute profile teeth are used more than those with cycloid AL teeth.

In involute gears, the pressure angle, from the start of the engagement of teeth to its end remains constant. It is necessary for smooth running and less wear of gears. But in cycloid AL gears, the pressure angle is maximum at the beginning of engagement, reduces to zero at pitch point, starts increasing again and becomes maximum at the end of engagement. This does not yield smooth running of gears.

The face and flank of involute teeth are generated by a single curve where as in cycloid AL gears, double curves are required for the face and flank respectively. Thus the involute teeth are easy to manufacture than cycloid AL teeth. The only disadvantage of involute teeth is that the interference occurs with pinions having smaller number of teeth.

2.4 Finite Element Method

FEM: Finite detail approach (FEM) is a numerical approach for finding approximate solutions to boundary cost problems. A boundary cost hassle is a differential equation together with a set of extra restraints, called boundary conditions. FEM uses numerous methods to minimize an errors function and produce a stable answer. Analogous to the idea that connecting many tiny immediately traces can approximate a larger circle, FEM encompasses all the strategies for connecting many straightforward detail equations over many small sub domain names, named finite elements, to approximate a greater complicated equation over a larger domain.

The subdivision of a whole domain into simpler parts has several advantages:

1. Accurate representation of complex geometry
2. Inclusion of dissimilar material properties
3. Easy representation of the total solution
4. Capture of local effects.

An average work out of the method involves dividing the domain of the trouble into a group of sub- domains, with each sub-domain represented via a set of detail equations to the authentic trouble, observed through systematically recombining all sets of detail equations into a global device of equations for the very last calculation. the global machine of equations has acknowledged solution strategies, and can be calculated from initial values of the original hassle to attain a numerical answer.

2.5 Calculix:

Calculix is an open supply finite element analysis utility with an explicit and implicit solver and a pre/publish processor. it's miles a package deal designed to resolve field troubles. The technique used is the finite element approach. With CalculiX Finite element fashions may be build, calculated and submit-processed. The pre- and post- processor is an interactive three-D-tool. The solver is capable of do linear and non-linear calculations. Static, dynamic and thermal solutions are to be had. Each programs can be used independently. due to the fact the solver uses the ABAQUS input layout it's miles feasible to apply industrial pre-processors as well. In turn the pre-processor is capable of write mesh related facts. Calculix is a totally powerful device of analysis, highly configurable allowing the user to have complete control over the analysis, with more than 18 types of analysis covering most fields of study finite element. Calculix's user can modify any variable on the analysis at discretion, the huge amount of information and documentation on the web make CalculiX a great alternative for the development of research projects.

2.6 CalculiX Graphics (CGX):

CalculiX consumer interface is CGX software, which lets in one to create the geometric version, making the mesh, generate the masses and constraints and put up-processing of facts. although it consists of a graphical show location and certain model selection activities are made viable via the pc mouse, maximum of the paintings is accomplished with the aid of typing textual content on a command line. Consequently it have to recognize the call and syntax of each command. no matter this the satisfactory of documentation and common sense handled on the command reasons this system is easily possible, in which skilled users would possibly consist of their own functions. for example a person may additionally want his personal functions to control the end result-statistics or he can also need an interface to study or write his personal effects layout.

After the analysis is completed (on CCX),the results may be visualized by means of calling the CGX software again in an unbiased consultation. This system is basically managed by the keyboard with man or woman instructions for every feature. Simplest a subset of instructions which can be most essential for submit-processing is also available through a pop-up menu. additionally, a reduce thru the model can be achieved which creates a segment and it's far feasible to zoom through the version. Shaded animations of static and dynamic outcomes, the commonplace shade plots and time records plots may be created.

2.7 AUTO-CAD:

AutoCAD is a software program utility for compter aided layout (CAD) and drafting. The software program helps both 2nd and three-D formats. The software program is evolved and sold by using Autodesk, Inc. It had end up the mostubiquitous layout software in the international, utilising functions consisting of polylines and curve becoming. The AutoCAD software program is now utilized in a number of industries, employed via architects, project managers and engineers. AutoCAD became first of all derived from a application called

engage, which changed into written in a proprietary language. the primary release of the software program used only primitive entities along with polygons, circles, strains, arcs and text to assemble complicated items.
DWG (drawing) is the native file layout for AutoCAD and a simple preferred for CAD information interoperability. The software program has also furnished aid for layout internet layout (DWF), a layout evolved by means of Autodesk for publishing CAD statistics.

Figure 6. Teeth Spur gear used for analysis

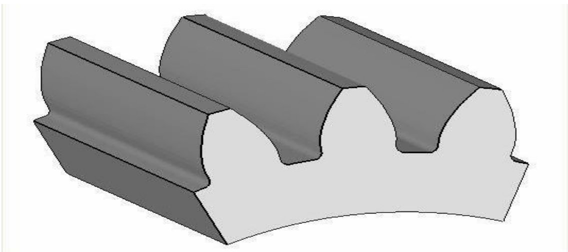


Figure 7. Extruded Spur gear

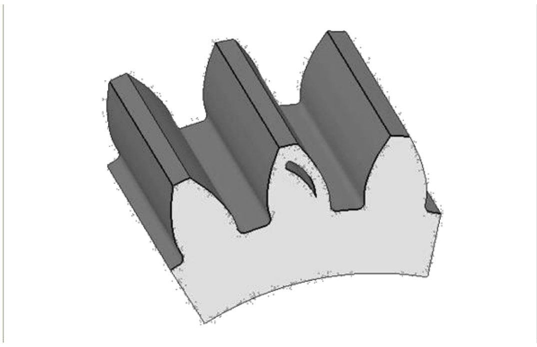


Figure 8. Spur gear with aero-fin hole

2.8 GMSH

GMSH is a three-dimensional finite detail mesh generator with a construct-in CAD engine and post-processor. Its design purpose is to offer a fast, light and person-pleasant meshing tool with parametric input and advanced visualization abilities. GMSH is built around 4 modules: geometry, mesh, solver and publish-processing. Geometry module is used to outline geometrical items inclusive of factors, traces, surfaces and volumes at the same time as mesh module is used to create mesh (nodes and detail topology). All commands of the modules are prescribed both interactively the usage of the graphical user interface (GUI) or in textual content files using GMSH's very own scripting language.

2.8 Finite Element Mesh Generation:

A finite element mesh is a positioning of a given subset of the three-dimensional area through essential geometrical factors of various shapes. The mesh era is executed inside the bottom-up glide i.e., lines are discretized first; the mesh of the traces is then used to mesh the surfaces; then the mesh of the surfaces is used to mesh the volumes. on this system, the mesh of an entity is best restrained by the mesh of its boundary. As an instance, in three dimensions, the triangles discretizing a floor can be compelled to be faces of tetrahedral within the very last 3D mesh best if the floor is a part of the boundary of a quantity. This mechanically assures the conformity of the mesh. each meshing step is restricted by means of a “length subject” (now and again referred to as “feature duration field”), which Gmsh 2.7 prescribes the preferred length of the factors inside the mesh. This length area can be uniform or specified by means of values related to points inside the geometry.

2.9 Gmsh is good at:

1. Generating 1D, 2D and 3D simplicial finite element meshes for CAD models in their native format
2. Specifying target element sizes accurately. It provides several mechanisms to control the size of elements in the final mesh: through interpolation from sizes specified at geometry points and using flexible mesh size fields.
3. Running on low end machines and machines with no graphical interface.
4. Visualizing and exporting computational results in great variety of ways.
5. Creating simple extruded geometries and meshes with the help of respective commands.

The problem of stress concentration is solved by removing material in the path of stress flow analogy.

When the material is removed in the path of flow analogy, the lines of force will travel uniformly. In our experiment, the material is removed in the shape of an aerodynamic fin which decreased the maximum principal stress at the fillet.

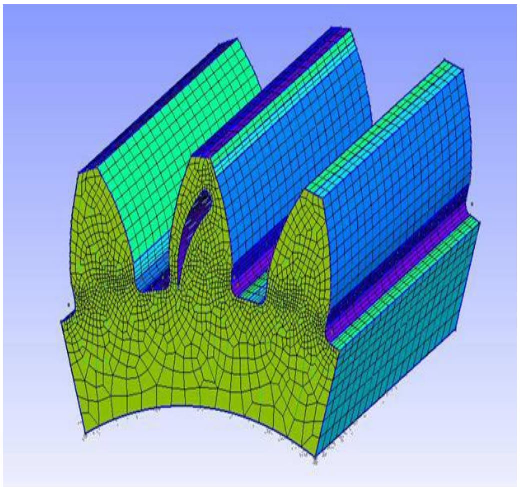


Figure 9. Spur gear with linear brick meshing

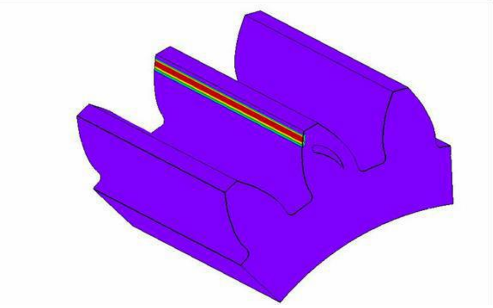


Figure 10. Spur gear loaded at HPSTC

2.10 Problem definition

A gear having specifications of Module (M) =2, No. of teeth(N)=25 to study and experiment is chosen from our reference thesis. A load of 89MPa 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. Then the stress relieving features are introduced, which are the circular holes of different dimensions which decreased the stress at the fillet to 124MPa. 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. A segment of three teeth is considered for analysis and stress relieving features of various sizes are introduced on gear teeth at various locations.

2.11 Laminar flow analogy:

For relieving stress concentration in gears conventional methods used are making Fillets, Notches and Holes.

1. Flow analogy with circular-shaped hole
2. Flow analogy with square-shaped hole.
3. Flow analogy with notch

The float analogy is used to visualise the stress awareness. It gives us a bodily photograph of why and in which pressure attention exists and it could be used as a device to decrease strain awareness. The course of drift analogy in tools starts from maximum point of software of load and ends at the basis fillet of the tooth. This shows that strains of pressure travel from contact point to root fillet, with gradual lower in width of the glide pattern. So, the strain awareness is extra at the fillet region which causes breakage of the enamel. The problem of strain attention is solved through getting rid of material in the direction of stress float analogy. Whilst the material is eliminated inside the direction of float analogy, the traces of force will journey uniformly. In our experiment, the fabric is eliminated inside the shape of an aerodynamic fin which reduced the most important pressure on the fillet.

2.12 Significance of Aero-fin hole:

The shape of aero-fin selected for this study is such that it modifies the stress flow into a smoother way, i.e., smoother flow of stress is achieved best by an aero-fin type of design because the curvy nature of this helps stress flow lines of stress to find a fluent path without any interruptions, the shape becomes narrowed towards the fillet end which will help the stress lines to flow smoothly to the fillet without increasing stresses.

III. RESULTS AND DISCUSSION

3.1 Results: Stresses & Displacements of analyzed gears

The gear without hole is examined to determine the maximum stress at the fillet and then theaero-fin hole is introduced to gear. The position and size of the aero-fin hole can be varied by changing input values of center of one of the arcs of hole and scaling factor using Parametrization in Gmsh. Now, the gear is experimented with different modifications done to the aero-fin hole by varying the parameters mentioned above. 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.

The co-ordinates of a focus point. It is considered as the centre of aero-fin hole which is used for transformation of entire hole.

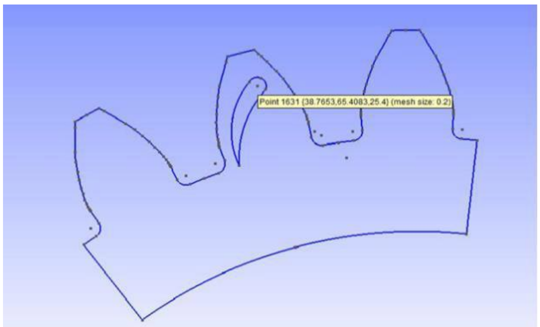
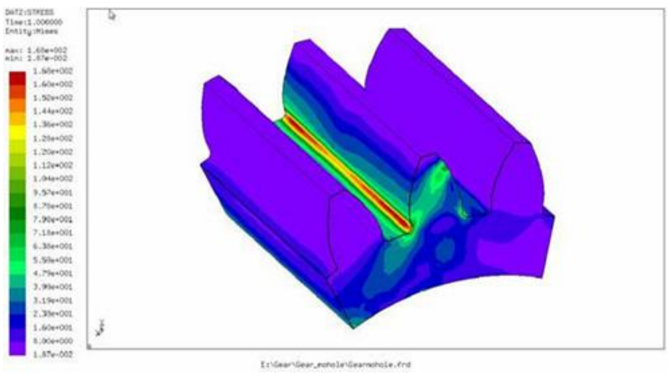
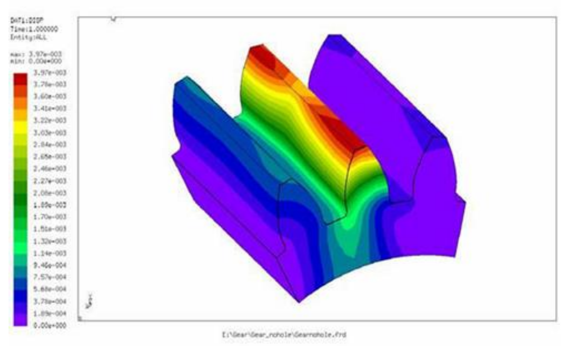


Figure 11. Centre of aero-fin hole

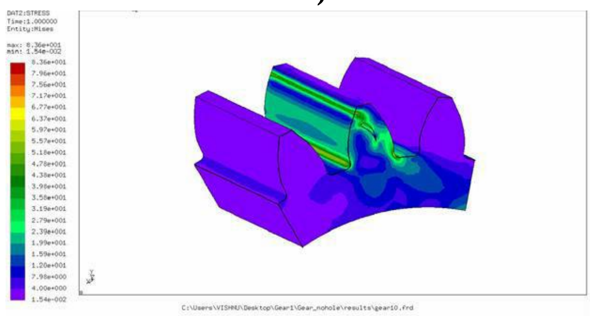
3.2 Stress and displacement in Normal Gear:

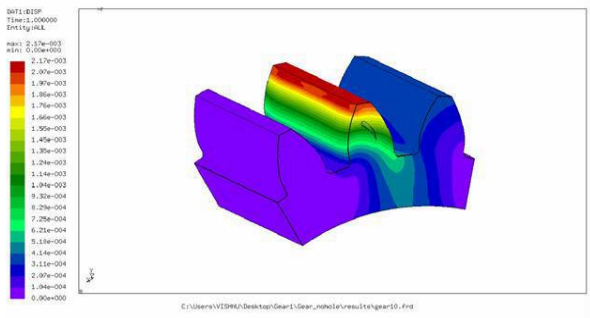
The maximum stress at the fillet is 168Mpa which much higher compared to the applied load on the gear.
According to the results tabulated above, the decrease in stress is 50.23%, whereas in the reference thesis stress is reduced by 24.07%. From this it can be inferred that aero-fin hole serves better as a stress relieving feature compared to circular hole.

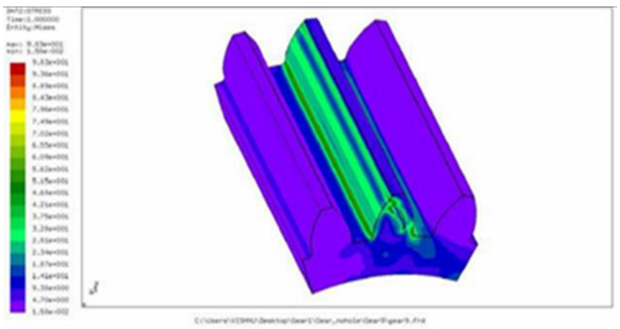


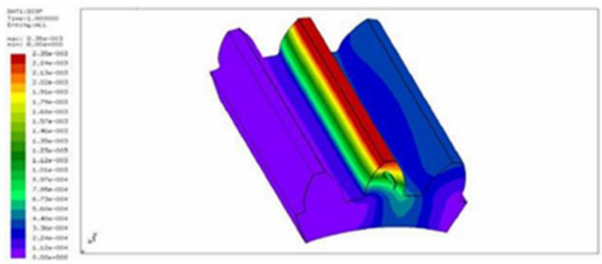


Stress and displacement in Gear (with aero-fin hole):





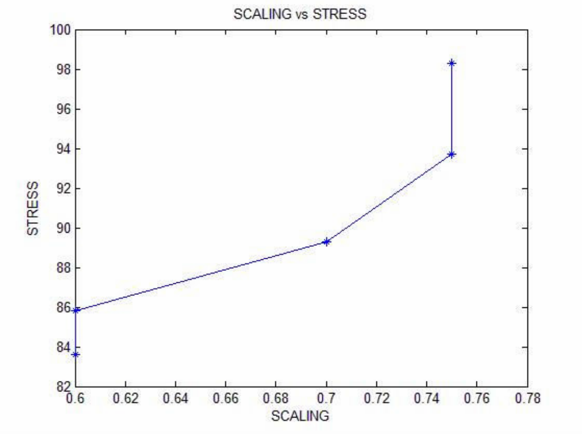




The maximum stress at the fillet is 98.3Mpa after the introduction of aero-fin hole with a scaling factor of 0.75.

3.3 Graphs

From the above graph it can be concluded that as the size of hole decreased, stress induced in the gear decreased significantly due to the modulation of hole in the stress flow direction.



From this graph, as the scaling decreased, the displacement also decreased. This is because as the hole size is less, material will be more due to which gear will be stiffer and finally displacement will be lower.

IV. Conclusion

The main aim of the above study is to relieve stress from the maximum value to as minimum as possible. So the highest point of contact of teeth is selected as pressure application point which causes highest stress.

Stress relieving feature having a shape of aero-fin is used in the path of stress flow which helped to regulate stress flow by redistributing the lines of force. This also yielded better results when compared to elliptical and circular holes.

In this study, the best result is obtained by introducing aero-fin hole at (38.7653, 65.9083, 0) and having scaling factor of 0.7. The result displayed a stress reduction by 51.23% and displacement reduction by 46.34%.

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