

Modeling and Reduction of Root Fillet Stress in Spur Gear Using Stress Relieving Feature

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Abstract: A gear is a component within a transmission device that transmits rotational forces. Gears are commonly used for transmitting power. Gear teeth failure due to fatigue is a common fact observed. Even a small reduction in the root tensile stress results in great raise in the fatigue life of a gear. They develop high stress concentration at the root and the point of contact. The repeated stressing on the fillets causes the fatigue failure of gear tooth. For many years, gear design has been improved by using better material, hardening surfaces with carburization and heat treatment, and shot peening to improve surface finish etc. Few more hard work have been made to improve the durability and strength by changing the pressure angle, using the asymmetric teeth, varying the geometry of root fillet curve and so on. The majority of the above systems don't ensure the compatibility of the current rigging frameworks. This work presents the possibilities of utilizing 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.

I. Introduction

A gear is a toothed wheel that works with others to alter the relation between the speed of a driving mechanism (such as the engine of a vehicle) and the speed of the driven parts (the wheels). Gears has always been of high importance in power transmission. The efficiency of any machine depends on the amount of power loss in the process. One of the best methods of transmitting power between two shafts is gears. Gears are mostly used to transmit torque and angular velocity. Gears are the most common means of transmitting power. Gears change the rate of rotation of shaft and also the axis of rotation. For high speed machinery, 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. The gear materials used for the manufacture of gears depend upon the strength and service conditions like wear and noise etc. The gears can be manufactured from metallic or non – metallic materials. The cast iron and steel is commonly uses for the manufacture of gears due to its good wearing properties, excellent machine ability and ease of producing complicated shapes by casting method. The non – metallic materials like wood, rawhide, compressed paper and plastic like Nylon, Acrylic and Polycarbonate etc are used for gears, especially for reducing weight and noise. Gear analyses in the past were performed utilizing analytical methods, which required a number of postulations and simplifications. In general, gear analyses are multidisciplinary, including cognate related to the tooth stresses and the failures. In this work first the solid model of the spur gear is made with relations and equations modeling option in Pro Engineer. After the modeling of spur gear the Segment of three teeth is considered for analysis, then the 3-D model is imported in AUTODESK INVENTOR the program reads the IGES file out from the pro engineering. Static analysis of a 3-D model has been performed by using AUTODESK INVENTOR.



Fig 1. Fatigue failure of gear tooth. (www.google.com)

The surface failures happening mostly because of contact fatigue are pitting and scoring. It is a phenomenon in which little particles are removed from the surface of the tooth because of the high contact stresses that are present between mating teeth. Pitting is really the fatigue failure of the tooth surface. Hardness is the essential property of the gear tooth that gives imperviousness to pitting. In other words, pitting is a surface fatigue failure because of numerous redundancies of high contact stress, which happens on gear tooth surfaces when a couple of teeth is transmitting power. Gear teeth failure due to contact fatigue is a typical marvel watched. Even a slight reduction in the stress at root brings about incredible expand in the fatigue life of a gear.

II. Literature Review

M.S.Hebbel, V.B.Math and B.G.Sheeparamatti [1] utilized elliptical and circular holes as a stress relieving feature. Analysis uncovered that, combo of elliptical and circular stress relieving features at particular, locations are beneficial than single elliptical, single circular, two circular or two elliptical stress relieving features. Ashwini Joshi, Vijay Kumar Karma [2] did a work which deals with the effect on gear strength with variation of root fillet design utilizing FEA. Circular root fillet outline is considered for analysis. The load application is done at the highest point of single tooth contact (HPSTC). Nidal H. Abu-Hamdeh and Mohammad A. Alharthy [3] did a work which deals with the effect of root fillet stress in spur gear by creating stress relieving holes in the gear body and face profile of the gear teeth. The results obtained showed that increasing the diameter size of hole/holes resulted in higher percentage of stress reductions compared to the pilot case. Furthermore, increasing the number of holes resulted in higher percentage of stress reductions compared to the pilot case, however gear rigidity in this case was highly affected. Dhavale A.S., Abhay Utpat [4] did a research study which deals with the effect of root fillet stress in spur gear by introducing stress relief features at stress zone. Analysis revealed that introduction of more than one stress relieving feature has added advantages in one of the most beneficial location principal stresses in the gear segment with a combination of two circular stress relieving features. Prof Vijaykumar Chalwa, Mr. Nagesh Kamanna, Asst Prof Prasad Nayak [5] used an Empirical relation to predict the probable percentage of reduction in root fillet stress in spur gear with circular stress relief feature. This work presents the possibilities of percentage of reduction in the root fillet stress of spur gear by introducing circular stress relieving feature of various sizes at different locations. Vivek Singh, Sandeep Chauhan, Ajay kumar [6] used a circular stress relieving feature in the stressed zone to the reduction of root fillet stress in spur gear. In this work stress relieving feature of various diameters are introduced in gear teeth. Analysis revealed that circular stress relieving feature at specific location is beneficial. Vivek Singh, Sandeep Chauhan [7] used a circular stress relieving feature in the stressed zone to the reduction of root fillet stress in spur gear. Analysis revealed that introduction of a circular hole below the root circle diameter between two teeth reduces the stress levels by a very high percentage about 42%. So by optimizing the diameter and position of the stress relief hole we can reduce the stress value in a gear tooth by a considerable amount without affecting the functioning of the gear. Mahesh. Badithe, Srimanthula Srikanth, Jithendra Bodapalli [8] the main objective of this study is to add different shaped holes to reduce stress concentration. A finite element model of Spur gear with a segment of three teeth is considered for analysis and stress concentration reducing holes of various sizes are introduced on gear teeth at various locations. Analysis revealed that aero-fin shaped hole introduced along the stress flow direction yielded better results. In this study, the best result is obtained by introducing aero-fin hole at (38.7653, 65.4083, and 0) and having scaling factor of 0.6. The result displayed a stress reduction by 50.23% and displacement reduction by 45.34%.

III. Modelling Of Involute Gear

The spur gear model is designed in Pro Engineer design modeller, which are having the following parameters. . Please note that this is the same gear geometry used by Mahesh. Badithe, Srimanthula Srikanth, Jithendra Bodapalli [8] Module (m) = 2 Pitch circle dia (d) = 50mm No. of teeth (N) = 25 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: Steel Properties of Steel: Young's modulus = 21000 MPa Poisson's ratio = 0.3 Part parameters are the necessary parameters defining the gear. These part parameters decide all the other parameters that define the gear tooth profile by utilizing the Tools/Relation menu. Figure 2 viewing the part parameters.

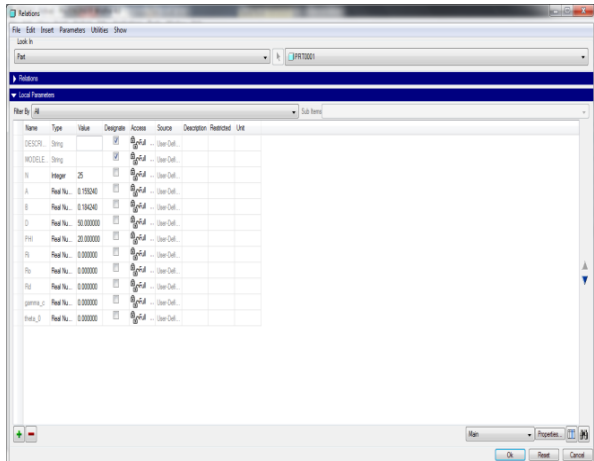


Fig. 2. Part Parameters

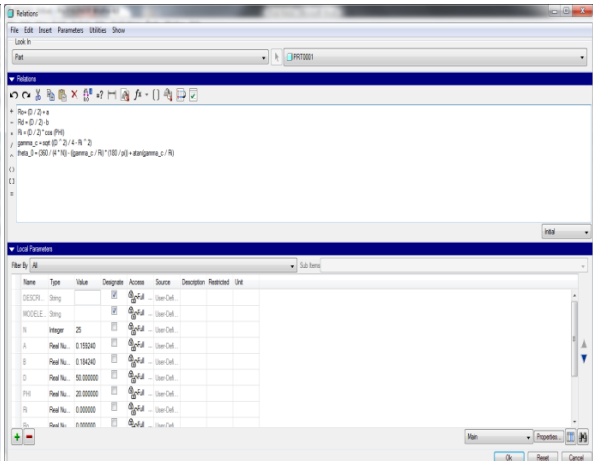


Fig. 3. Tools / Relations menu

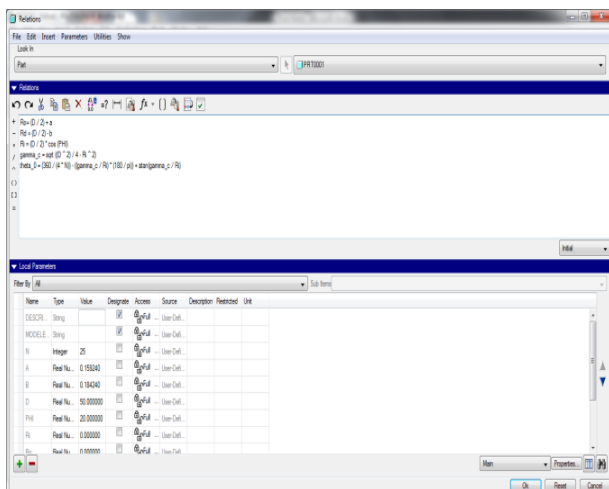


Fig. 4. Part Relations



Fig. 5. Datum Curve Relations

Drawing the circle focused on the sketch references for the extrusion profile and taking the extrusion depth equivalents to the thickness of gear. By utilizing the Tools/ Relations Menu we characterize relations between the sketch dimension and the part parameters. Figure 3 is demonstrating the Tools/ Relations Menu. In the wake of characterizing these relations, the circle should have the diameter equivalents to the measurement of the addendum diameter of the gear blank. Figure 4 is demonstrating the part relations for getting the addendum diameter.

Selecting From Equation from the Insert/ Model Datum/ Curve Menu. We take “PRT_CSYS_DEF” as a default coordinate system. Taking coordinate system cylindrical type. In this condition a Notepad window will pop up where we can enter all mathematical equations for the datum bend. As demonstrated in the Figure 5. Review after passage of every last one of parameters will demonstrate the involute bend over the gear blank as shown in the Figure 6. Presently we have an involute curve at one side of the gear blank, by mirroring the bend about the axis we get the C shaped profile made up of two involute profiles. In next step heading off to the Tools/ Relations menu and setting the inner arc to the value of parameter Rd. In the wake of extruding the C shaped profile through the entire depth of the gear blank at long last we get the space between the two gear teeth. Figure 8 is demonstrating the space between the two gear teeth.

From the newest extruded feature in the model tree and selecting the pattern, in the top dashboard we select the following parameters;

1. Pattern type: Axis pattern
 2. Axis for pattern: A-1 at the centre of the gear.
 3. Number of copies: Equals to the number of teeth here 25.
- Included angle of the pattern: 360°

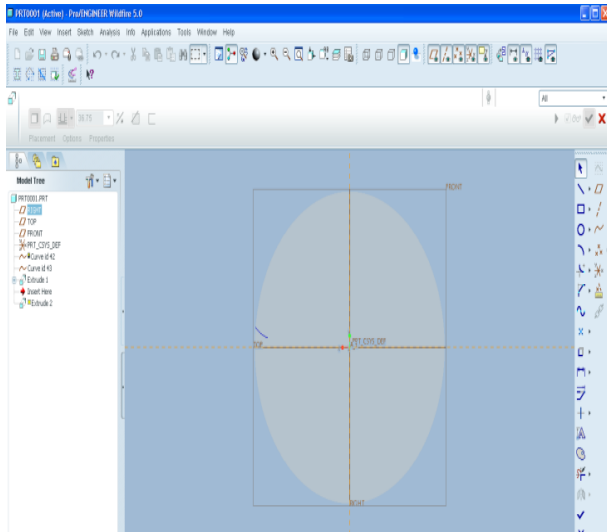


Fig. 6. Involute Profile over the Surface of Gear Blank

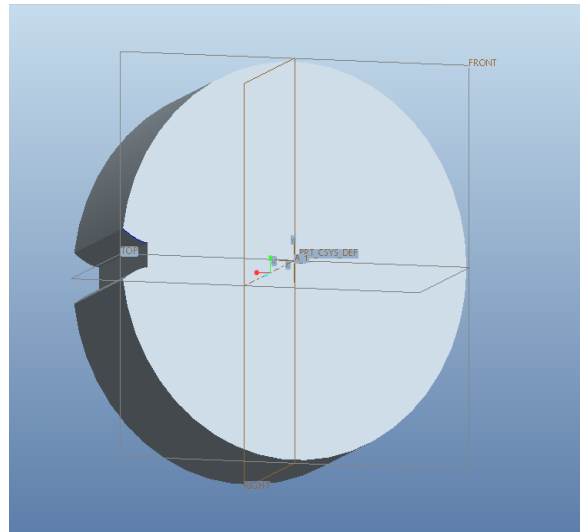


Fig. 7. Gear Blank with Tooth Space

After accepting the settings we get the involute gear with the desired number of the teeth. As shown Figure 8.

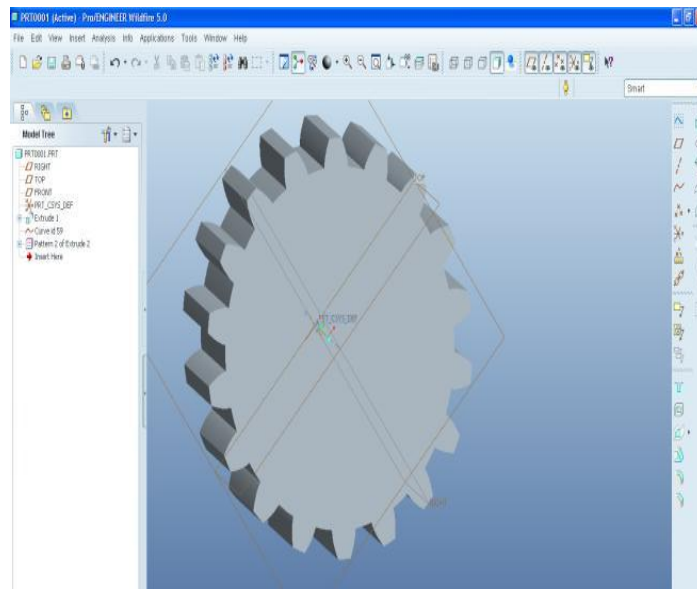


Fig. 8. Gear Model

IV. Finite Element Mesh Generation

A finite element mesh is a situating of a given subset of the three-dimensional space by basic geometrical components of different shapes. The mesh generation is performed in the base up stream i.e., lines are discretized first; the grid of the lines is then used to mesh the surfaces; then the mesh of the surfaces is utilized to mesh the volumes.

V. Problem Definition

A gear having specifications of Module (M) =2, No. of teeth (N) =25 to study and experiment is chosen from our reference paper. A load of 89MPa as given in paper is applied at the highest point of contact of gear teeth. The stress at root fillet region is of the value 61.48Mpa and displacement is 0.0000746mm. 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 oval shape 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.

Laminar flow analogy

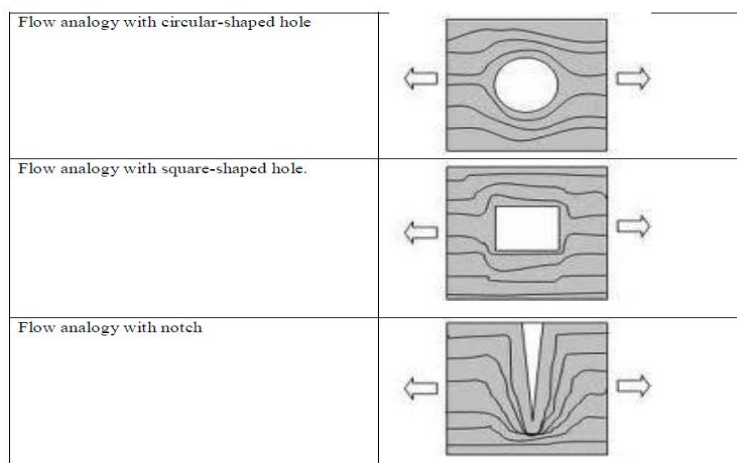


Fig.9. Laminar flow analogy (www.google.com)

The flow analogy is utilized to imagine the stress focus. It provides for us a physical picture of why and where stress focus exists and it might be used as a tool to diminishing stress fixation. The way of flow analogy in gear begins from highest point of application of load and ends at the root fillet of the tooth. This shows that lines of force travel from contact point to root fillet, with continuous decrease in width of the flow pattern.

Significance of oval shape hole

The shape of oval selected for this study is such that it changes the stress flow into a smoother way, i.e., smoother flow of stress is accomplished best by an oval 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 end which will help the stress lines to flow smoothly to the fillet without increasing stresses.

Stresses & Displacements of analyzed gears

The gear without hole is examined to determine the maximum stress at the fillet and then the oval shape hole is introduced to gear. The position and size of the oval hole can be varied by changing input values of center of one of the arcs of hole. Now, the gear is experimented with different modifications done to the oval 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 Fig illustrates the coordinates of a focus point. It is considered as the center of oval hole which is used for transformation of entire hole.

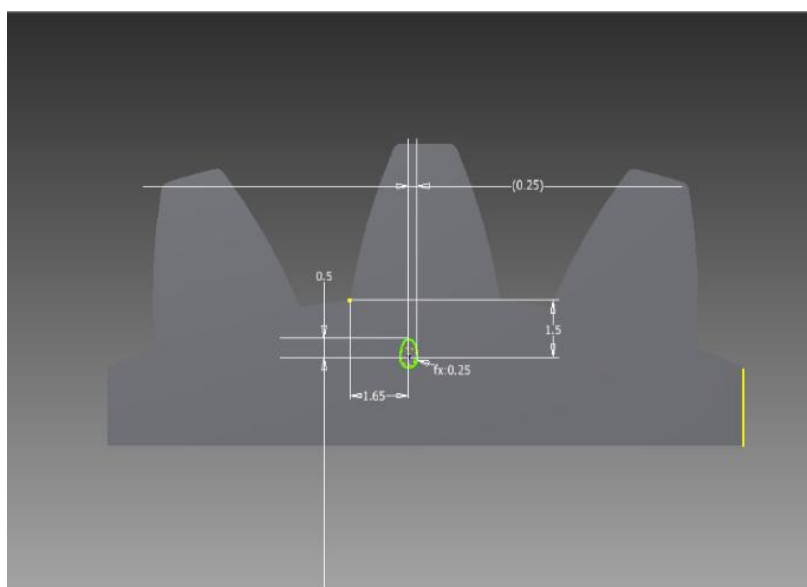


Fig.10. Centre of oval hole

Stress and displacement in Normal Gear

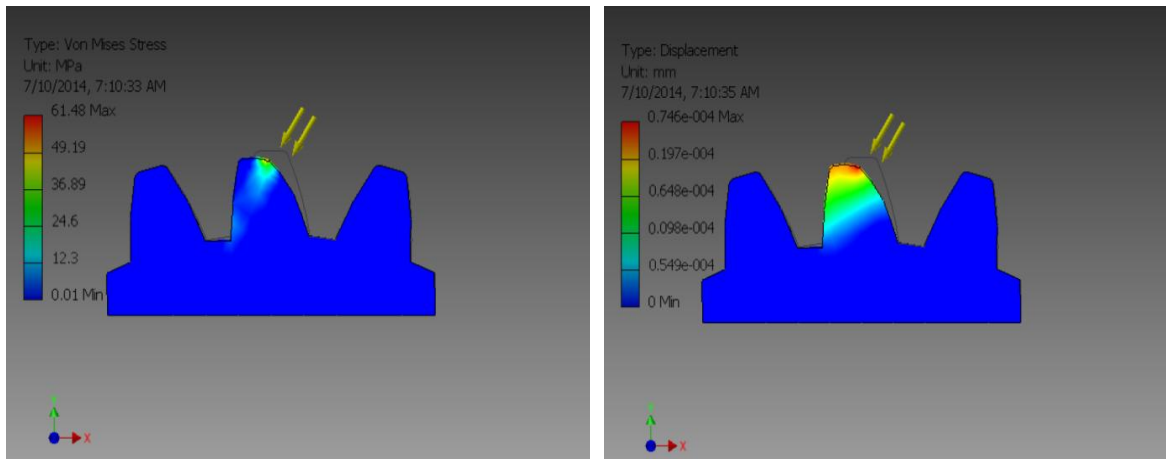


Fig.11. stress and displacement of normal gear

The maximum stress at the fillet is 61.48 Mpa and displacement is 0.0000746mm.

Stress and displacement in gear with oval shape hole (1st position)

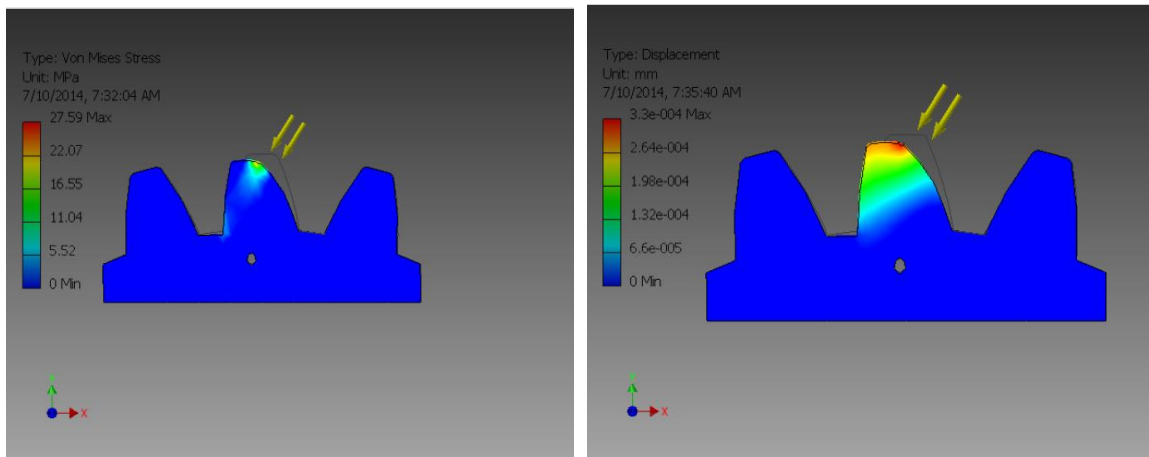


Fig.12 . Stress and displacement in gear with oval shape hole (1st position)

The maximum stress at the fillet is 27.59 Mpa and displacement is 0.000329998 after introducing oval shape hole.

Stress and displacement in gear with oval shape hole (2nd position)

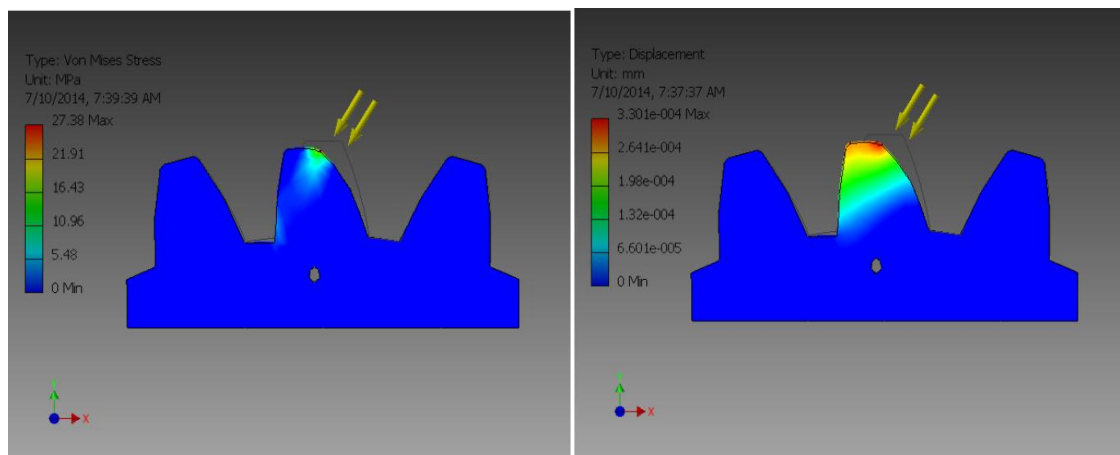


Fig.13. Stress and displacement in gear with oval shape hole (2nd position)

The maximum stress at the fillet is 27.38 Mpa and displacement is 0.000330067 after shifting oval shape hole.

Stress and displacement in gear with oval shape hole (3rd position)

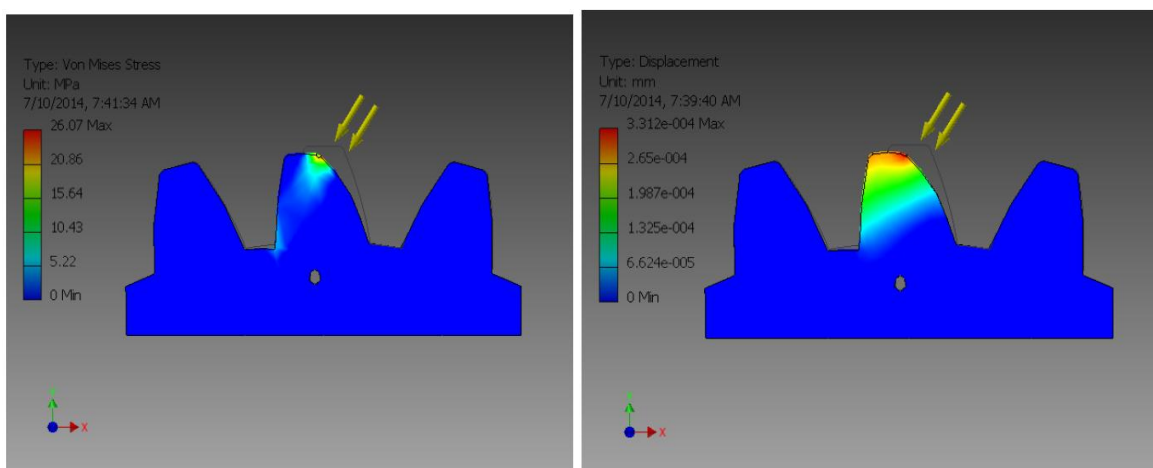


Fig.14. Stress and displacement in gear with oval shape hole (3rd position)

The maximum stress at the fillet is 26.07 Mpa and displacement is 0.00033119 after shifting oval shape hole.

Stress and displacement in gear with oval shape hole (4th position)

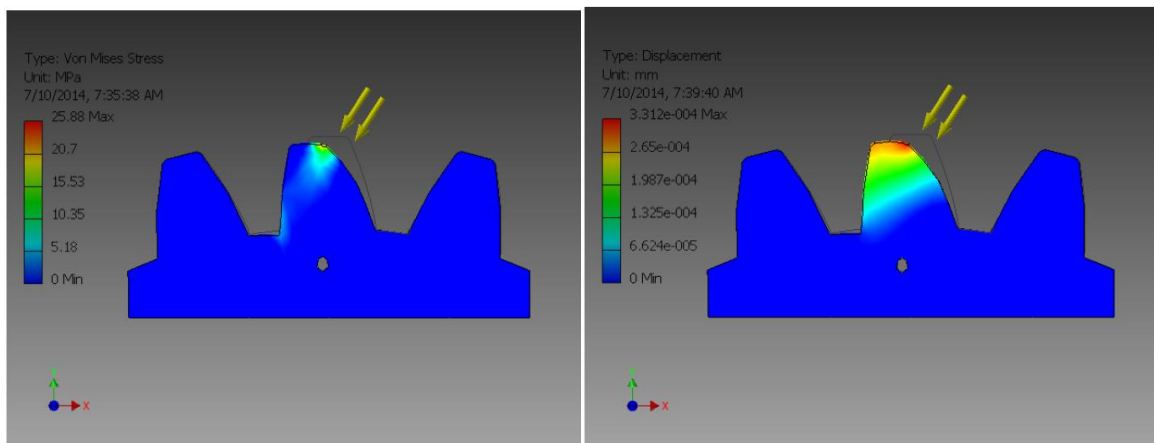


Fig.15. Stress and displacement in gear with oval shape hole (4th position)

The maximum stress at the fillet is 25.88 Mpa and displacement is 0.000332257 after shifting oval shape hole.

Stress and displacement in gear with oval shape hole (5th position)

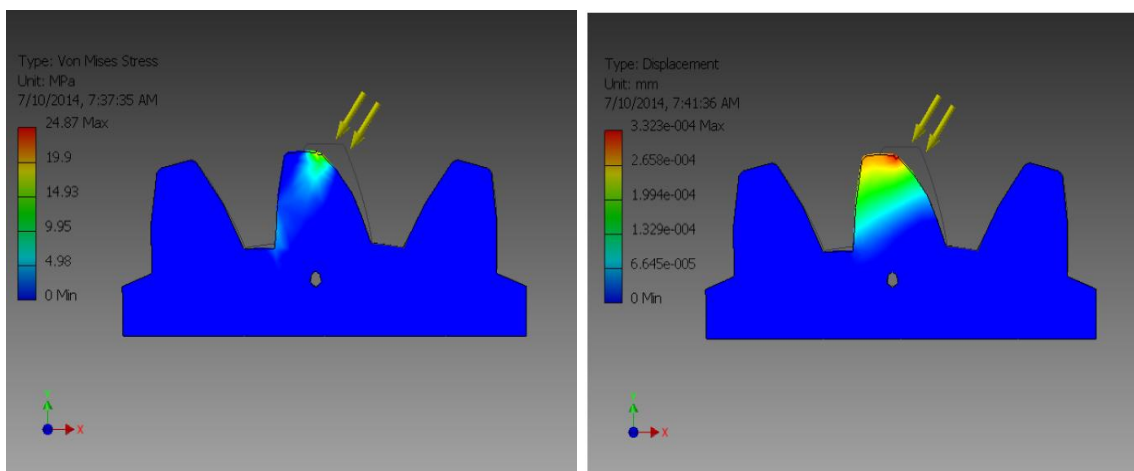


Fig.16. Stress and displacement in gear with oval shape hole (5th position)

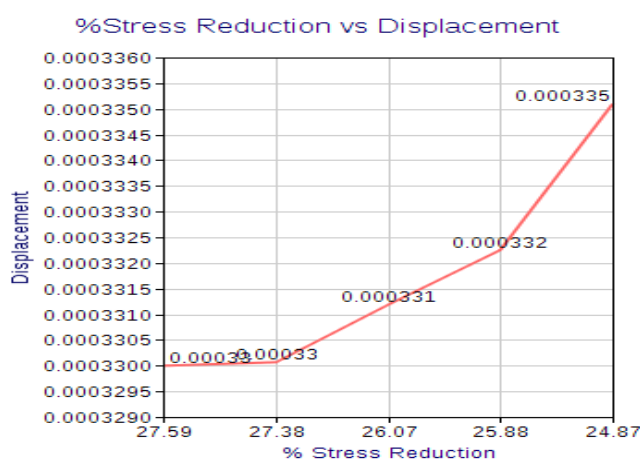
The maximum stress at the fillet is 24.87 Mpa and displacement is 0.000335102 after shifting oval shape hole.

VI. Results Of The Analysed Gears Are Tabulated Below

Positions of oval	Coordinates of oval centre(mm)		Maximum Stress (Mpa)	% Reduction in stress	Safety factor Maximum (ul)	Displacement (mm)
	x	y				
1	1.65	1.5	27.59	55.15	15	0.000329998
2	1.75	1.6	27.38	55.46	15	0.000330067
3	1.75	1.4	26.07	57.59	15	0.00033119
4	1.85	1.5	25.88	57.9	15	0.000332257
5	1.75	1.5	24.87	59.54	15	0.000335102

According to the results tabulated above, the decrease in stress is 59.54%, whereas in the reference paper [8] stress is reduced by 50.23%. From this it can be inferred that oval shape hole serves better as a stress relieving feature compared to other stress relief feature.

Graph



From the above graph it can be concluded that as the % Stress Reduction Increased, displacement also increased.

VII. Conclusion

The main aim of the above study is to relieve stress from the maximum value to as least as could be allowed. 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 oval is used in the path of stress flow which helped to regulate stress flow by redistributing the lines of force. This additionally yielded better results when compared to elliptical, circular and aerodynamic holes.

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