

Study of Circular and Elliptical Holes as a Stress Relieving Feature in Spur Gear

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ABSTRACT: Gear drive is used to transmit power from one shaft to another when distance between two shafts is very small. There are several failure mechanisms for spur gears. Bending failure of the teeth is one of the main failure modes. In this research work, various stress relieving features are studied. Single circular holes, two circular holes, one circular hole in combination with elliptical hole are used to study the effect of these features in stress reduction. Modeling is done with drafting software AutoCAD. Finite element based software ANSYS is used for this work. Initially using AGMA method bending stresses were determined analytically. A good agreement was found between analytical & finite element results of bending stress.

KEYWORDS: Bending stress, Circular Hole, Elliptical Hole, Stress relieving feature, Finite Element Analysis

I. INTRODUCTION

1.1 Overview

Gearing is one of the most critical components in a mechanical power transmission system, and in most industrial rotating machinery. It is possible that gears will predominate as the most effective means of transmitting power in future machines due to their high degree of reliability and compactness. In addition, the rapid shift in the industry from heavy industries such as shipbuilding to industries such as automobile manufacture and office automation tools will necessitate a refined application of gear technology. There are several failure mechanisms for spur gears. Bending failure of the teeth is one of the main failure modes. The bending stresses in a spur gear are another interesting problem.

1.2 Objective of Present Work.

- To analyze the bending stress in spur gears using FEM
- To study the effect of circular hole as a stress relieving feature for gears
- To observe the effect of more than one circular hole for stress reduction in gears
- To examine the results of combination of circular hole & elliptical hole on the stresses in the gear

II. LITERATURE REVIEW

2.1 Literature Review

Nidal H. Abu-Hamdeh and Mohammad A. Alharthy (2014) studied stress relieving features to reduce the root fillet stress in spur gear. A pilot model was established to predict Von Mises stress at the root fillet of the gear without holes and was used as a reference model. Finite element modeling was adopted using Abaqus package. The predicted stresses were compared with stresses obtained by AGMA analytical solution. A good agreement was found in the comparison between the calculated and predicted stresses. Then, two other models, namely first model and second model, were built to investigate the effect of various hole parameters (number, diameter, location, angle). The first model was performed by creating hole/holes in the gear body. The second model was performed by creating hole/holes in the face/profile of the gear. 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, but gear rigidity in this case was highly affected.

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V.Rajaprabakaran, Mr.R.Ashokraj studied different shaped holes to reduce stress concentration. A finite element model of Spur gear with a segment of three teeth was considered for analysis and stress concentration relieving 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.

M. S. Hebbal & et al (2014) made an attempt to establish the empirical relations to predict the percentage of reduction of the root fillet stress in a spur gear due to elliptical stress relief features (SRF). To modify the stress field in a spur gear to reduce the stress concentration using elliptical stress relief feature has added advantage over the circular stress relief features, because it has more parameters such as major diameter, ratio of major to minor diameter and orientation of its axis to regulate stress field. An investigation on root fillet stress in a spur gear with an elliptical stress relieving feature was carried out using finite element method. Based on the finite element analysis carried out nine empirical relations are proposed. With these relations it is possible to predict the percentage of reduction of root fillet stress in spur gear within 2 percentages of deviation

Prof. Vijaykumar Chalwa & et. al (2013) carried out two categories of systematic analyses using finite element model of spur gear. In the first category of analyses emphasize was given to determine the maximum root fillet stress which was required as reference to determine the stress reduction factor. In addition to this, the effect of number of teeth, pressure angle, and basic parameters of rack cutter on root fillet stress was investigated. In second category which was the prime focus of this work; the effect of introducing geometric stress relief feature is carried out. The program was coded in ANSYS Parametric Design Language (APDL). They have determined some empirical relation with the help of which prediction of root fillet stress in gears can be done.

Vivek Singh & et al (2012) in their paper present the stress redistribution by introducing the stress relieving features in the stresses zone to the reduction of root fillet stress in spur gear. In this work circular stress relieving features were used & better results were obtained. A finite element model with a segment of three teeth was considered for analysis & stress relieving feature of various diameters were introduced on gear teeth. Analysis revealed that circular stress relieving features at specific locations are beneficial.

M. S. Hebbal & et. al (2014) investigated the stress at the gear tooth profile by replacing the conventional trochoid fillet by polynomial curves. The circular root fillet profile was constructed by drawing an arc tangent to working profiles and root circle and this arc was taken as reference root fillet to generate alternative root fillet profile. The arc was divided into six segments. New fillet profiles are constructed by displacing the middle points radially using different relations and keeping the end points fixed. The improved root fillet profiles resulted into reduction of bending stress by 9 to 12 percentage. The results presented were based on two dimensional finite element analyses. (FEA)

Here for this research work a pinion used in reduction gear box is chosen for study.

III. METHODOLOGY OF THE RESEARCH

3.1 Methodology

In the research work, a pinion (with module 4.5 mm & 13 teeth) from a reduction gear box is taken. Model of three teeth is done using drafting package AutoCAD. The 'IGES' files are exported. These files are imported into finite element based analysis software ANSYS. After meshing with a quadrilateral element with mid-side node, boundary conditions are applied by restricting motions of three sides of the gear as shown in figure 1. Tangential load of 1523 N is applied at the top of the tooth. The bending stresses are observed during post processing. Input properties are as below.

Table 3.1(a) Input properties

Young's Modulus	2.1×10^5 Mpa
Poisson's ratio	0.3

A comparison of the bending stress obtained by finite element analysis is done with the analytical value of bending stress. There is good agreement between the results obtained by these two methods. The finite element analysis is then extended for bending stress reduction using various stress relieving features. These are single circular hole, two circular holes & a circular hole with one elliptical hole.

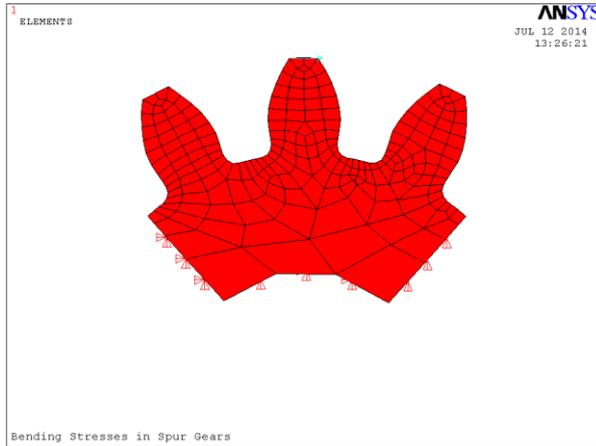


Fig.3.1(a) Meshed Model of Pinion along with load condition & boundary condition

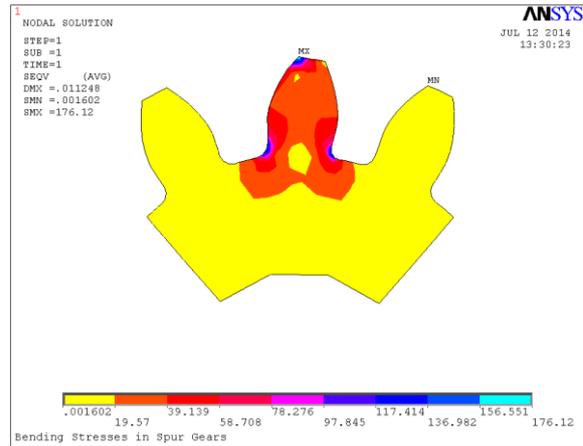


Fig.3.1(b) Bending Stresses (Von Mises)

From figure 3.1 (a) shows meshed model of pinion. Meshing is done by using quadrilateral 8 node elements. Movement of three sides if the sectors of pinion are restricted in all directions. A point load of $1523/20 = 76.15$ N/mm is applied at the tip of the teeth.

Figure 3.1 (b) shows Von Mises stresses (Bending stresses). The maximum Von Mises stress is 176.12 MPa whereas maximum deformation is 0.011248 mm. Maximum deformation is at the top of the teeth which is far away from the base of the teeth. As the load is applied at the tip of the tooth, the maximum stress will be at the tip as this load is point load. So neglecting the stresses at the point of application of load, stresses at the root of the teeth are observed.

The bending stresses obtained by **Finite Element analysis** are **78.276 Mpa**. The maximum Von Mises Stress is 176.12 MPa. The maximum deformation is 0.011248 mm. **Analytical value** of bending stress is **78.7 MPa**.

% Error was 0.5387

The arrangement of stress relieving feature holes is made as below.

Table 3.1(b) Locations of holes

Radius of Hole Center Locations (mm)	Offset Distance of line parallel to teeth profile (mm)	Angles from Centerline of teeth (°)
30.187	0.5	7.5
29.187	0.75	8.5
28.187	1	9.5
27.187	1.25	10.5
26.187		11.5
		12.5

The centers of holes lie at the intersection of curved lines (of radii as indicated in the first column of the table 3.1(b) & offset lines lying at distances indicated in second column of the above table. Few hole centers (of holes lying at the base of the teeth near the root are lying at the intersection of radial lines drawn at different angles as indicated third column of the table 3.1(b) & offset lines described earlier.

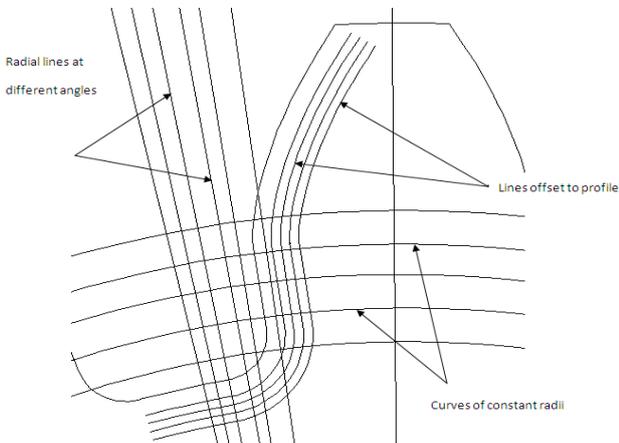


Fig. 3.1(c) Location of holes

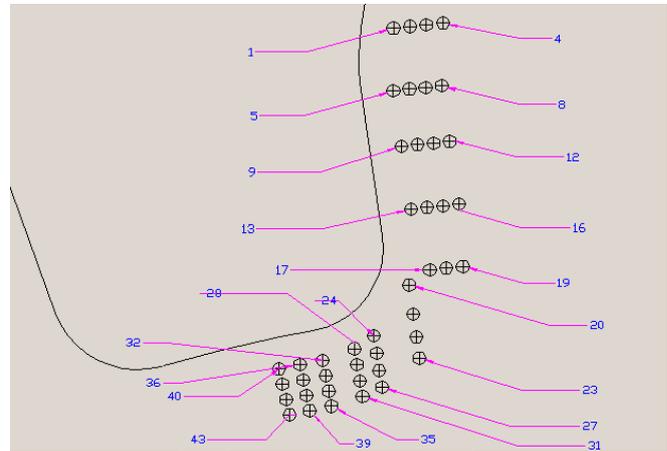


Fig. 3.1(d) Numbering of circular holes

The figure 3.1(c) show the exact locations of hole centers. Figure. 3.1(d) shows numbering of circular holes.

Also the numbering system followed for the same is shown above. The numbering system is used as number of holes is more & it is difficult to describe position of each hole while discussing the result obtained.

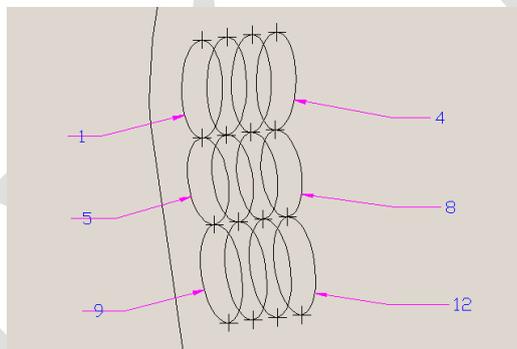


Fig. 3.1(e) Arrangement of elliptical holes & their numbering

The figure 3.1 (e) shows the exact location of the elliptical holes along with the numbering system followed.

Also using the centers of earlier circular holes as end points of the major axis of ellipse, the elliptical holes are made to make use with one circular hole.

IV. RESULTS & DISCUSSIONS

4.1 SINGLE CIRCULAR HOLE AS STRESS RELIEVING FEATURE

All the above holes are tried but there was no reduction in the stresses [The results of these are given in this paper due to space constraint]. So, few more holes are tried which are chosen arbitrarily. The coordinates of centre of hole are given with reference to the centre of the pinion which lies at a distance of 75 mm in X direction & 25 mm in Y direction from origin.

Following are the results obtained during the above study.

Table 4.1(a) Effect of holes chosen arbitrarily

Sr. No.	X Coordinate (mm)	Y Coordinate (mm)	Radius of hole (mm)	Max. Von Mises Stress (MPa)	Max. Deflection (mm)
1	74.05	51.2	0.8	175.951	0.011389
2	74.05	51.2	1	184.058	0.011489
3	74.05	51.2	0.7	183.681	0.011361
4	75	51	0.8	184.507	0.011317
5	73	51	0.8	184.581	0.011770
6	74	52	0.8	184.548	0.011528
7	74	50	0.8	181.541	0.011333
8	77	51	0.8	227.879	0.012255
9	74.15	51.2	0.8	180.175	0.011377
10	73.95	51.2	0.8	178.052	0.011401
11	73.85	51.2	0.8	179.843	0.011431
12	74	51.2	0.8	177.9	0.011404
13	74.05	51	0.8	181.903	0.011363

During this study, it is seen that there is only slight reduction in maximum stress for a hole lying at a X = 74.05 mm & Y = 51.2 mm & having a radius = 0.8 mm.

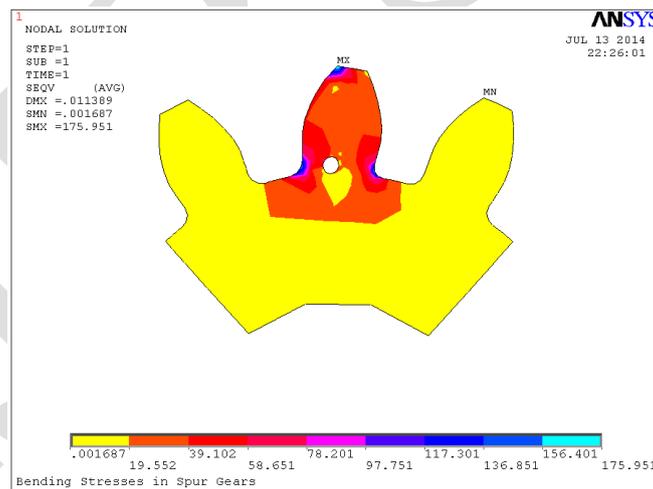


Fig. 4.1(a) Von Mises Stresses for Single Circular hole as a stress relieving feature

The above figure 4.1 (a) shows the reduced value of Maximum Von Mises stress which is 175.951 MPa. The % reduction in stress is determined as below.

$$\% \text{ Reduction in stress} = (176.12 - 175.951) * 100 / 176.12 = 0.09595$$

As this reduction is very less, more than one circular hole as a stress relieving feature is tried. For all other values of X & Y coordinate of centre of hole, the stresses are higher than those present in the model without any stress relieving feature.

4.2 TWO CIRCULAR HOLES AS A STRESS RELIEVING FEATURE:

The holes finalized in the earlier study are used for this study also but only combination of different holes is done & effect is observed.

The results obtained for various combinations of holes are given in table 4.2 (a). Radius of holes = 0.5 mm

Table 4.2(a) Effect of two circular holes

Hole Numbers	Max. Von Mises Stress (mm)	Max. Deflection (mm)
2 & 17	283.04	0.012346
6 & 21	309.796	0.012402
10 & 25	218.4	0.012402
14 & 29	299.471	0.012552
17 & 33	278.583	0.012362
4 & 19	184.7	0.011857
8 & 23	185.435	0.011930
12 & 27	186.763	0.011994
16 & 31	176.187	0.011997
19 & 35	185.768	0.011868
31 & 43	237.383	0.011858
12 & 23	184.009	0.011995
16 & 27	182.219	0.012027
27 & 43	183.359	0.011834

The first column indicates the combination of the holes studied. Second & third columns indicate the maximum Von Mises stress & maximum deformation respectively. It is seen that there is no reduction in the stress.

4.3 Effect of arbitrarily chosen holes

As there is no reduction in the stresses with the earlier chosen holes, new holes are selected arbitrarily. Here one hole is kept at fixed position & other hole is moved at different places to observe the effect on the stresses.

The coordinates of the fixed hole are X = 74.05 mm, Y = 51.2 mm & Radius of fixed hole = 0.8 mm

Table 4.3(a) Effect of location & radius of second circular hole

Sr. No.	X Coordinate (mm)	Y Coordinate (mm)	Radius of 2 nd hole (mm)	Max. Von Mises Stress (MPa)	Max. Deflection (mm)
1	70	46	0.8	178.695	0.011528
2	70	48	0.8	180.243	0.011737
3	71	48	0.8	175.977	0.011803

4	71.5	48	0.8	183.178	0.011804
5	71	48	0.9	178.351	0.011944
6	71	48	0.7	176.227	0.011701
7	72	49	0.8	214.311	0.012006
8	71	47	0.8	172.314	0.011618
9	71	49	0.8	218.772	0.012377
10	71	46	0.8	183.955	0.011538
11	71	46.5	0.8	174.066	0.011562
12	71	47	0.7	175.668	0.011553
13	71	47	0.9	175.9	0.011664
14	70	47	0.8	180.301	0.011606
15	72	47	0.8	178.239	0.011592

Also the variation is done in fixed hole.

New coordinates of fixed holes X= 73.05 mm, Y= 51.2 mm, Radius of hole = 0.8 mm

Coordinates of second hole X = 71 mm, Y= 47 mm, Radius of hole = 0.8 mm

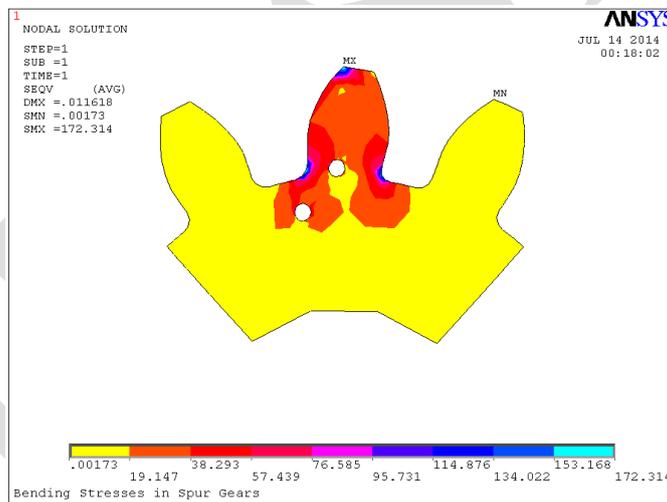


Fig. 4.3(a) Von Mises Stresses for Two Circular holes as a stress relieving feature

The maximum Von Mises stress is 181.131 MPa & Max. Deformation is 0.012011 mm as shown in figure 4.3(a).

Thus it is seen that the lowest value of Von Mises stress obtained using two circular holes as a stress relieving feature is 172.314 mm. (For X = 71 mm, Y = 47 mm & Radius of second hole is 0.8 mm.

% Reduction in stress = (176.12 – 172.314) *100 / 176.12 = 2.161

Thus it is seen that a stress relieving feature of two holes is better than a single hole.

4.4 ONE CIRCULAR HOLE & ONE ELLIPSE AS A STRESS RELIEVING FEATURE

As there was less reduction in the stresses using two circular holes as stress relieving feature, a combination of a circular hole & an elliptical hole is tried. The results are as below.

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Initially hole No. 31 is kept constant. Out of the different ellipses drawn, effect of each one is observed with the circular hole. Here radius of circular hole is taken as 0.5 mm.

Table 4.4(a) Effect of combination of one elliptical (varying location) & fixed circular hole

Elliptical hole Number	Circular Hole Numbers	Max. Von Mises Stress (Mpa)	Max. Deflection
2	31	186.623	0.011654
4	31	183.481	0.011639
6	31	177.807	0.011652
8	31	184.308	0.011669
10	31	183.118	0.011731
12	31	180.74	0.011694
5	31	179.91	0.011661

The major axis of ellipse was having a length equal to the distance between two adjacent hole centers & minor axis was 0.2035. Observing the earlier values of the stresses obtained with single circular hole & two circular holes, the location of the circular hole is changed & the effect of combination of this hole & every elliptical hole is studied. Here details are as below.

Table 4.4(b) Effect of combination of one elliptical & one fixed circular hole for different cases

Sr. No.	Ellipse No.	X Coordinate (mm)	Y Coordinate (mm)	Radius of hole (mm)	Max. Von Mises Stresses (Mpa)	Max. Deflection (mm)
1	2	74.0	51.2	0.8	183.912	0.011483
2	2	74.05	51.2	0.9	184.024	0.011519
3	4	74.05	51.2	0.8	184.023	0.011472
4	6	74.05	51.2	0.8	180.826	0.011490
5	8	74.05	51.2	0.8	183.997	0.011500
6	10	74.05	51.2	0.8	184.713	0.011574
7	12	74.05	51.2	0.8	183.280	0.011539
8	2	71	47	0.8	183.901	0.011589
9	4	71	47	0.8	183.113	0.011577
10	6	71	47	0.8	180.058	0.011596
11	8	71	47	0.8	184.462	0.011604
12	10	71	47	0.8	183.914	0.011667
13	12	71	47	0.8	181.578	0.011634

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From the table 4.4 (b), it is seen that the stress is less (but still greater than the one without stress relieving feature) with ellipse No. 6, the same is used for further study.

The values of the stresses are obtained for various locations of circular hole and fixed elliptical hole No. 6 are as below.

Table 4.4(c) Stress & Deformation for fixed elliptical hole & varying circular hole

Sr. No.	X Coordinate (mm)	Y Coordinate (mm)	Radius of hole (mm)	Max. Von Mises Stresses (Mpa)	Max. Deflection (mm)
1	72	47	0.8	181.052	0.011564
2	70	47	0.8	181.094	0.011574
3	71	48	0.8	181.003	0.011785
4	71	46	0.8	180.180	0.011505
5	71	47	0.7	179.937	0.011539
6	71	47	0.5	181.122	0.011454
7	75	49	0.8	181.387	0.011439
8	75	51	0.8	183.020	0.011421
9	74	49	0.8	179.293	0.011462
10	73	49	0.8	180.188	0.011636
11	74	49	0.7	181.364	0.011449

Here it is observed that there is no stress reduction using for a combination of elliptical & circular hole stress relieving feature.

Figure 4.4 (d) shows the stresses which are lowest. [Sr. No. 9 in above table 4.4(c)].

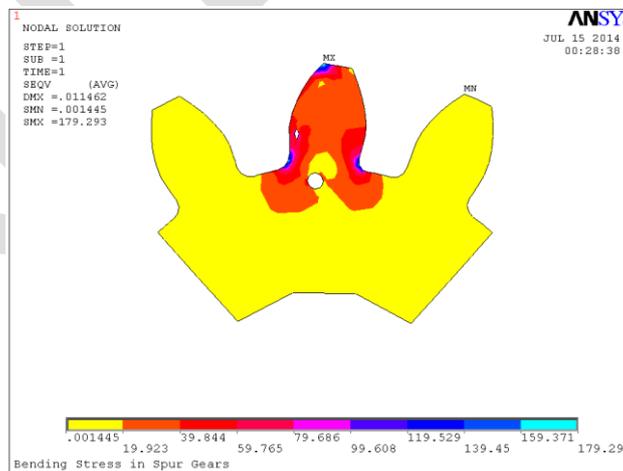


Fig. 4.4(d) Von Mises stresses for One Circular hole & one elliptical hole as a stress relieving feature

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At the end, again the variation in the minor axis length was made. Also the major axis was increased keeping same minor axis & the effects are observed. In both the cases, the stresses are again higher. So, elliptical feature along with circular is not useful here.

V. CONCLUSION

In this research work, various stress relieving feature used for gears are studied. Following things can be concluded from the above work.

- Very less reduction in stress is possible with single circular hole as a stress relieving feature.
- Two circular holes as a stress relieving feature give more reduction than single circular hole.
- There is no reduction in the stress for a combination of a circular & elliptical hole.
- Stresses are very much sensitive to the location & size of stress relieving features.
- It is very difficult to determine the correct location of a stress relieving feature.
- It is also very difficult to determine the correct size of the stress relieving feature.

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