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Root Fillet Stress Reduction in Spur Gear having Undercut

Sowjanya B[1], Hebbal M. S[2]

[1] *Department of Mechanical Engineering, Yenepoya Institute of Technology, Moodbidri, India*
[2] *Department of Automobile Engineering, Basaveshwar Engineering College, Bagalkot, India*

Abstract- **Generally the gear tooth fails due to high stress at root region. Even a slight reduction in the stress results in greater increase in life of the gear. For a compact design of a gear box, it is necessary that the number of teeth of the pinion should be less .For a given pressure angle there is a limiting value on minimum number of teeth below which undercut occurs. The spur gear with undercut suffers in strength severely. Therefore the gears with undercut are generally avoided. The present work explores the possibilities of increasing the strength of spur gear having undercut thereby reduce the overall size of the gearbox. A systematic study is conducted to understand the effect of introducing circular stress relief features on stress distribution in a statically loaded spur gear. Circular stress relief features of various sizes at different radial distance and angular position are placed around the end point on critical section on loaded side of the gear tooth profile. Effect of these stress relief feature on maximum stress are investigated.**

I. INTRODUCTION

Gears are the most common means of transmitting motion and power in the modern mechanical engineering world. They form vital elements of mechanisms in many machines such as automobiles, metal cutting machine tools, rolling mills and transmitting machinery. Toothed gears are used to change the speed and power ratio as well as direction between an input and output shaft[1-3].

Spur Gear Spur gears are the simplest and most common type of gear. Their general form is a cylinder or disk. The teeth project radially, and with these "straight-cut gears",the leading edges of the teeth are aligned parallel to the axis of rotation. These gears can only mesh correctly if they are fitted to parallel axles.

Law of Gearing "A common normal to the tooth profiles at their point of contact must, in all positions of the contacting teeth, pass through a fixed point on the line-of-centers called the pitch point."

Undercutting in Gears In the production of spur gears, the gear teeth will have a portion of the involute profile removed, if the number of teeth to be cut in the blank is less than a minimum number. This minimum number of teeth depends on the hob tooth geometry. This action is the result of involute interference between the tip of the hob tooth and flank of the gear tooth and is known as undercutting. The undercut not only weakens the tooth with a wasp-like waist, but also remove some of the useful involute adjacent to the base circle. **Hebbal**, *et.al* [4] investigated 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 **Math** *et.al* [5] proposed an approach for determination of geometry of spur gear tooth fillet. An equation is developed to determine the point of tangency of root fillet and involutes tooth profile on the base circle for a spur gear without undercutting. The standard gear with teeth number below a critical value is automatically undercut in the generating process. The condition for no undercutting in a standard spur gear is given by,

$$\text{Maximum addendum}=ha<=\frac{mZ}{2}\sin^2(\phi) \qquad (1.1)$$

And, the minimum number of teeth is,

$$Z_c=\frac{2}{\sin^2(\phi)} \qquad (1.2)$$

The minimum number of teeth free of undercutting decreases with increasing pressure angle.

For 14.5 degree pressure angle, the value of Z_c is 32.

For 20 degree pressure angle, the value of Z_c is 18.

Undercutting is undesirable because of losses of strength, contact ratio and smoothness of action. To prevent undercut,a positive correction must be introduced. Ex $\phi=20^{0}$, Z=10,Xm=+0.5

$$X_m=(d/2)*\sin^2(\phi) \qquad (1.3)$$

The condition to prevent undercut is spur gear is

$$m-X_m<=\frac{mZ}{2}\sin^2(\phi) \qquad (1.4)$$

The number of teeth without undercut will be

$$Z_c = \frac{2(1-x)}{\sin^2(\phi)} \quad (1.5)$$

The co-efficient without undercut is

$$X = 1 - \frac{Z_c}{2}\sin^2(\phi) \quad (1.6)$$

Profile shift is not merely used to prevent undercut. It can be used to adjust center distance between two gears[6-8].

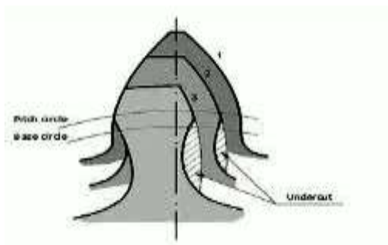

Fig.1.1 Undercut gear

II. OBJECTIVE OF THE PRESENT WORK

The objective of the present work is to investigate the effect of stress relief feature on root fillet stress in spur gear with undercut. ANSYS solution processor is used for obtaining the solution for the finite element model that is generated within the Preprocessor

III. GEAR TOOTH PARAMETERS CONSIDERED FOR ANALYSIS

The parameters are considered for investigations of gears are given in table 1. The details of materials and load applied on the gear are as follows.

Nature of load= Static

Material=Steel

Modulus of Elasticity (E) $=2*10^{11}$ N/mm^2

Poisson's ratio (ν) =0.3

Table 1

The parameters considered for the study

Parameters	**Value**
Pressure Angle	20^o
Addendum factor	1.25
Dedendum factor	1
No. of teeth	16,14,12
Module	10
Rim thickness	1.25 times module

3.1 ANSYS solution processor

Loads can be applied using either preprocessor or the Solution processor. It is necessary to define the analysis type and analysis options, apply loads, specify load step options, and initiate the finite-element solution. The analysis type to be used is based on the loading conditions and the response which is wished to calculate. The ANSYS program offers the following analysis types: static (or steady-state), transient, harmonic, modal, spectrum, buckling, and sub structuring.

This processor is used for obtaining the solution for the finite element model that is generated within the Preprocessor, Important tasks within this processor are:

- Applying Loads and boundary conditions.
- Obtain solution

3.2 Applying loads

Load states include boundary conditions and externally applied forcing functions. Load states in structural analysis are defined by forces, pressures, inertial forces (as gravity) and specified displacements, all applied to the model. The loading may be in the form of a point load, a pressure or a displacement in a stress (displacement) analysis. The loads may be applied to a point, an edge, a surface or even a complete body [9-12].The loads should be in the same units as the geometry and material properties specified.Loads can be applied on nodes by means of concentrated forces and moments. Inertia loads are those attributable to the inertia of a body, such as gravitational acceleration, angular velocity, and acceleration. A concentrated load applied on a node is directly added to the force vector. However, the element interpolation functions are used to compute the equivalent forces vector due to distributed loads [13]. For 1500 rpm and 5 HP Torque.

1HP=745.699872 watts

1HP=0.745699872 kilowatts.

5HP=3.73 KW.

$$V = \frac{\pi DN}{60} \quad (4.2)$$

= (3.142*10*16*1500)/60=12.566 m/s

$$W_t = \frac{P}{V} C_s$$

C_s =1.25 steady loads

$$W_t = \frac{3728.9}{12.56637} * 1.25$$

W_t =370.89 N

$W_T = W_N * \cos\phi$ (4.3)

$W_N = W_T / \cos\phi$ =370.89/Cos (20) =394.69 N

$W_R = W_N * Sin\phi$ (4.4)

W_R =394.69*sin (20)

W_R =134.99 N

Similarly, for 14 and 12 number of teeth Radial and Tangential loads are calculated are shown in table 2.

Table 2 Load applied at the tip of the tooth along x and y axis for different no of teeth

SlNo	No of teeth	Load in x-axis	Load in y-axis
1	16	370.89 N	134.99 N
2	14	424.07 N	154.35 N
3	12	494.54 N	180.0 N

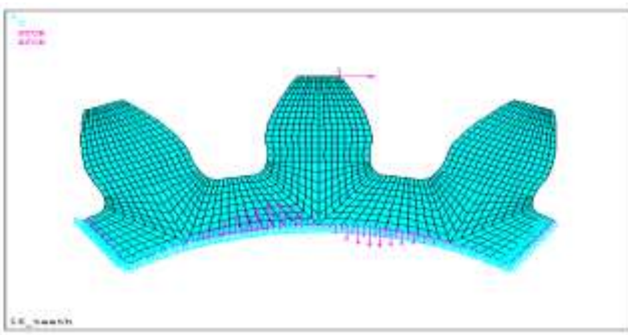

Fig1.2 Finite Element Analysis of three gear teeth segment

IV. RESULTS AND DISCUSSIONS

Maximum stress concentration for 16 teeth spur gear without hole is 235 N/mm^2. Table 3 Overall % Reduction for 16 teeth with different distances and hole diameters

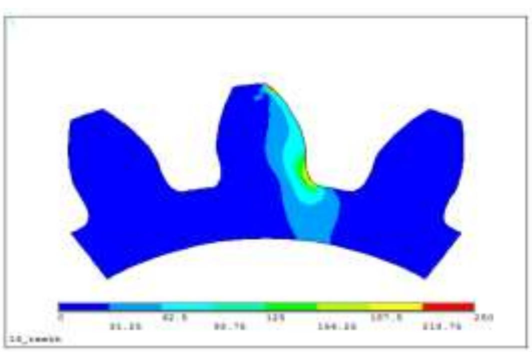

Fig.1.3 Maximum stress concentration for 16 teeth without hole

Table 3 Overall % Reduction for 16 teeth with different distances and hole diameters

Distance	Angle					
	Dia 2mm		Dia 3mm		Dia 4mm	
6	1.9	300	6.7	300	7.4	300
7	1.4	300	6.9	285	6.1	315
8	2.0	315	3.0	180	3.0	300

Maximum stress concentration for 14 teeth spur gear without hole is 289 N/mm^2

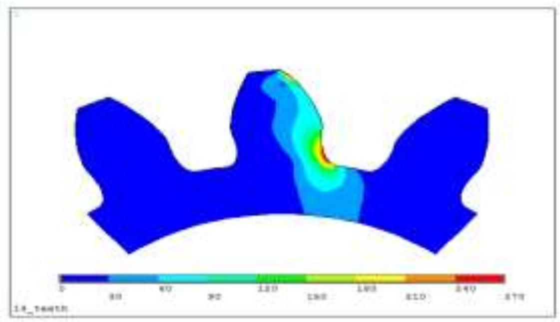

Fig.5.5 Maximum stress concentration for 14 teeth without hole.

Table 4 Overall % Reduction for 14 teeth with different distance and hole diameter

Distance	Angle					
	Dia 3mm		Dia 4mm		Dia 5mm	
6	5.9	300	10.1	300	-	-
7	4.6	300	7.0	300	10.3	300
8	3.1	300	4.9	300	6.8	300

Maximum stress concentration for 16 teeth spur gear without hole is 373 N/mm^2. Table 4 shows overall % Reduction for 14 teeth with different distance and hole diameter. Table 5 shows overall % Reduction for 12 teeth with different distance and hole diameters

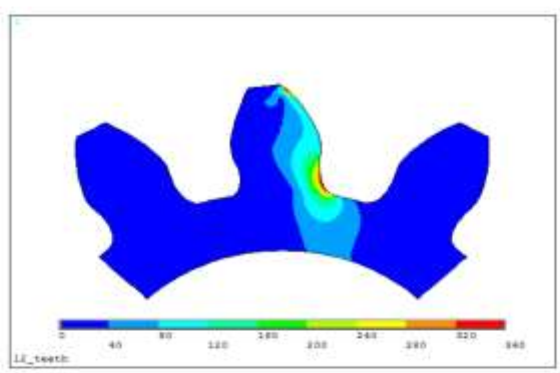

Fig.5.9Maximum stress concentration for 12 teeth without hole

Table 5 Overall % Reduction for 12 teeth with different distance and hole diameters

Distance	Angle					
	Dia 3mm		Dia4mm		Dia 5mm	
6	7.62	195	1.2	300	-	-
7	3.4	315	7.8	300	9.8	300
8	3.24	315	4.5	300	6.2	300

V. CONCLUSION

It is possible to reduce the stress at the root fillet by introducing stress relief of appropriate shape and size at suitable location. The percentage reduction in maximum principal stress is insignificant in gears with profile shift factor less than zero.The highest reduction in maximum principal stress of 7.4%, 10.3%, and 3.6% is attained for one circular hole SRF respectively.

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