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The Effect of Stress Relief Feature (SRF) on Fatigue Life of Spur Gear

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Abstract*: *The fatigue is common phenomenon observed in gear teeth failure. The presence of root fillet stress at the tooth root is a primary reason behind the failure of gears. It has direct impact on human life and property. The focus of the present work is to estimate the increase in the fatigue life of spur gear by reducing maximum root fillet stress on gear teeth with the introduction of circular Stress Relief Feature (SRF) of appropriate, size at strategic location. Introducing SRF is a potential method to improve gear life by redistributing stresses around stress concentration zone. The reduction in maximum stress developed in spur gear results into increased fatigue life. Spur gears with different geometry (Pressure angle 25^0, number of teeth 12, module 10, zero profile shift factor and zero factor of radius) are considered for investigation. These gears are intended to transmit ten horse powers (7.457 kilo Watt) at 1800 rpm. Analysis revel substantial increase in fatigue life in most of the cases. The increase in life ranges from 7.7×10^5 load cycle to 5.80×10^{10} load cycle. It is equivalent to 7.12 to 537037 hours of working life of gear. In few cases the gears do not fail by fatigue.

Keywords: Fatigue life, ANSYS, Root fillet stress, Stress Relief Features (SRF).

I. INTRODUCTION

A gear is a mechanical member used for power transmission in many industrial applications such as automobile, textile looms, aircraft and submarine etc. In order to improve the life of a gear large amount of effort has been put from many years. Many researchers suggested improving the life of a gear by using high strength material, hardening the surface by heat treatment, carburization and shot peening to improve surface finish.

A limited work has been carried out to reduce the stress concentration in gears and thereby improving the strength and durability of the gears. In the design viewpoint, the fatigue strength and wear are the most important criteria because each gear tooth may experience billions of load cycles.

Fatigue failure is a common phenomenon observed in gears. It is the main reason behind the catastrophic failure of mechanical components. It has direct impact on human life and property. Toth and Yalema [1], Yarema [2] and Schutz [3] explicitly presented that the knowledge of fatigue life hails from late historical era to beginning of industrial era. Smith, R.A. and Hilmansen, S. In 2004 [4], observed the deep cognition of fatigue on railway axels.

In order to improve the fatigue life of gears the stress redistribution technique with introduction of Stress Relief Features (SRF) is a potential method according to the many researchers. Introduction of circular, elliptical, aero fin hole or combination of these SRF of different dimension at different location has proved beneficial. In view of this, a systematic study is carried out to estimate gear fatigue life.

II. LITERATURE REVIEW

L. Fredette and M. Brown [5] studied the reduction of tooth root fillet stress of spur gear by introducing the stress relief features at different location. The main aim was to find most benifical effects of relief hole size and location on critical stresses of spur gear. The reduction of root fillet stress was up to 8.8 percent for single hole drilled at tooth root while the combination of holes reduced stress to 15.8%.

M.S.Hebbal [6] studied the redistribution of tooth root tensile stress by the introducing Stress Relief Features (SRF) in high stressed region. Combinations of circular and elliptical holes of different sizes at various locations are introduced on a three teeth finite element model of spur gear. The combined effect of circular and elliptical relief features found more beneficial than the individual circular and elliptical features. As the location of the SRF approaches the higher stress concentration zone the stress reduction was appreciable.

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V.Rajprabakaran, R.Ashokraj [7] deals with reduction of root fillet stress on gears teeth by introducing an aero fin shaped SRF. Introduction of aero fin hole will make stress flow smoother and reduce stress concentration. A finite element model of spur gear with segment of three is considered for analysis. Stress Relief Features of different dimension at various locations reduced the stress concentration significantly.

Deep Singh, Rohit Rajvaidya [8] the study showed the reduction of fillet stress using stress redistribution technique by introducing the oval shaped relief hole on gear teeth which ensured the stress flow in smoother way. The oval hole is positioned at five different places for analysis and analysis showed the increase in stress reduction percentage.

Vivek Singh, Sandeep Chauhan and Ajay Kumar [9] a three spur gear model is considered for the study, a load of 200 N was applied at tip of the gear. A program was devised to automate the process of creation of model, meshing, applying the constraints and display of results. The analysis showed that the there will be a considerable amount stress reduction by the introduction of the stress relieving feature. The position of the SRF varied and analysed for better location to obtain the maximum reduction in the root fillet stresses.

G.Gonzalez, R.J.Garcia Martin [10] studied the fatigue life estimation by using strength life approach. The Study considered cylindrical steel gears of sugar cane mill for analysis. The fatigue life estimation was based on the AGMA standard considering pitting resistance of gear teeth. The fatigue life of cylindrical steel gears found to be in good agreement with results of field studies.

Anand Kalani Rita Jani [11] work showcased the possibilities of stress reduction by using the stress redistribution techniques by the introduction of stress relief features and fatigue life estimation. A three teeth spur gear model is used for the study by applying load at highest point single tooth contact, the analysis is performed at three different regions i.e parallel to dedendum, along the root fillet and along the root fillet, with offset distance of 0.5 mm and 0.2 mm diameter hole was fixed at all positions. The study showed that hole below the dedendum has reduced stress by 23% and increase fatigue life by 53 times.

III. MODELLING OF SPUR GEAR AND FATIGUE LIFE ESTIMATION

A. Finite Element Modelling of Spur Gear

Finite element analysis is the powerful numerical technique which handles intricate parts, different materials, any boundary conditions. The finite element analysis involves creating the geometry of the model, meshing, and applying boundary conditions and seeking solutions which satisfy the boundary conditions applied. This follows the interpretation of results to arrive at meaningful conclusions. The material and the gear parameters considered for the analysis are shown in table III.1 and III.2 respectively.

Table III.1 Steel Grade-I through hardened

BHN	250
Young's modulus	2.1×10^^{5} MPa
Poisson's ratio, (γ)	0.3
No of load cycles	10$^{\wedge 5}$

Table III.2 Spur gear dimensions[6]

Parameter	Range
Pressure angle (α)	20^0, 22.5^0 and 25º
No. of teeth(z)	30, 50 and 70
Power (P)	10 hp
Rotational speed (n)	1800 rpm
Module (m)	10
Face width (b)	110 mm
Profile shift factor (Sf)	-0.2, -0.1 and 0
Radius factor (rf)	0, 0.2 and 0.25

A spur gear three teeth model with meshing and boundary condition are as shown in figure III.1, III.2 and III.3 respectively for the sample case (Pressure angle 25^0, number of teeth 12, module 10, zero profile shift factor and zero factor of radius).

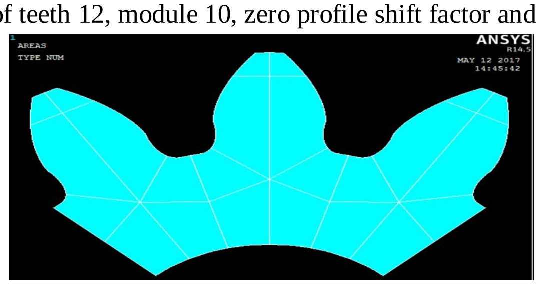

Fig III.1 spur gear teeth model

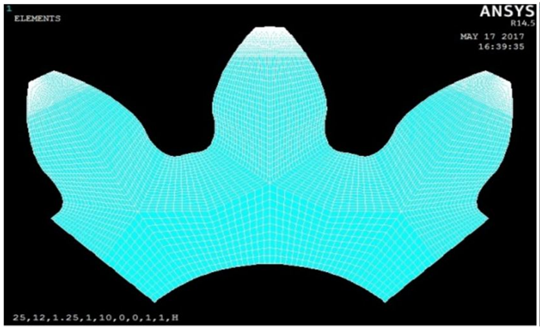

Fig. III.2 spur gear teeth meshed model

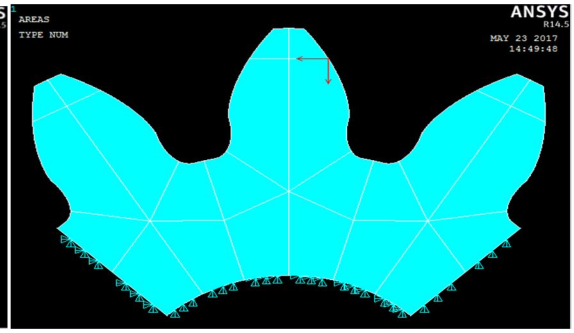

Fig. III.3 spur gear three teeth segment with boundary condition

B. Stress Relief Feature (SRF)

The SRF are geometrical shapes which are introduced on the gear teeth to reduce stress concentration by redistributing stress on gear teeth. The SRF can be of circular, elliptical, or aero fin shapes, in the present work the circular stress relief features of radii 1.25, 1.50, 1.75, 2.0 times module are introduced at the radial distance of 7.0, 7.5, 8.0 and 8.5 from end point of loading side of critical section along 315^0 line. A SRF introduced gear teeth model is as shown in III.4 for the sample case.

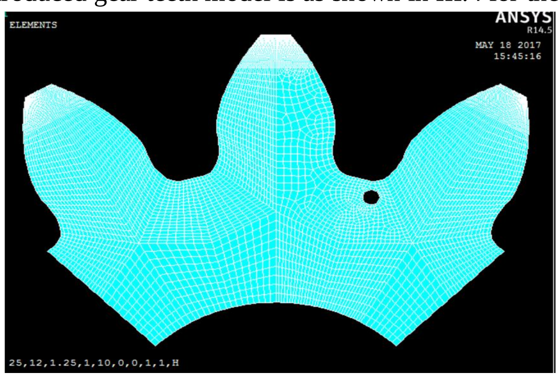

Fig. III.4 shows SRF introduced three teeth gear model

C. Fatigue Life of Spur Gear

The fatigue life estimation is based on AGMA standard procedure for spur gear design. The design procedure includes the calculation allowable bending stress which is a function of bending stress number and stress cycles factor given by relation [12].

$$\sigma_{b.allow} = \frac{\sigma_{bn} \times Y_N}{S_F \times K_T \times K_R} \text{ .... (1)}$$

Where,

$\sigma_{ballowable}$ = allowable bending stress in MPa

σ_{bn}= bending stress number in MPa

Y_N= stress cycles factor

S_F= Safety factor

K_T= Temperature factor

K_R= Reliability factor

Bending stress number is given by [12]

$$\sigma_{bn} = 77.3(HB) + 12800 \text{ psi} \quad \text{............................... (2)}$$

$$\sigma_{bn} = 77.3(250) + 12800$$

$$\sigma_{bn} = 221.469 \text{ MPa}$$

$S_F = 1$

$K_R = 1.00$ for 0.99 reliability, $K_T = 1.0$ for temperatures up to 120º C

Referring to equation (1), Allowable bending stress,

$$\sigma_{b.allow} = \frac{221.469 \times 1.5}{1 \times 1 \times 1}$$

$$\sigma_{b.allow} = 332.20\ \text{MPa}$$

D. *Number of Load Cycles (N)*

In order to calculate the fatigue life of the spur gear, the maximum reduction in root fillet stress is considered and reduced tooth root fillet stress is taken as maximum allowable stress for which the stress cycles factor need to be evaluated. Calculation of new stress cycles factor, $Y_N = \frac{(\sigma_{b.allow}.K_T.K_R.S_F)}{\sigma_{bn}}$

$$Y_N = \frac{227.942 \times 1 \times 1}{221.469}$$

$$Y_N = 1.03$$

From [12] for Y_N =1.03, and $Y_N = 1.6831 \times N^{-0.0323}$ .... (3)

$$1.03 = 1.6831 \times N^{(-0.0323)}$$

$$N = 4101634.625 \text{ cycles}$$

IV. RESULTS AND DISCUSSIONS

A. *Maximum Root Fillet Stress without Stress Relief Features*

The maximum root fillet stress without SRF is 247.32 MPa and it is smaller than the permissible bending stress for the material considered. The allowable bending stress obtained from calculation using AGMA equation is 323.20 MPa, which is much higher than the maximum stress obtained from the analysis i.e 247.32 MPa for the sample case (Pressure angle 25^0, number of teeth 12, module 10, zero profile shift and zero radius factor). It is as depicted in F

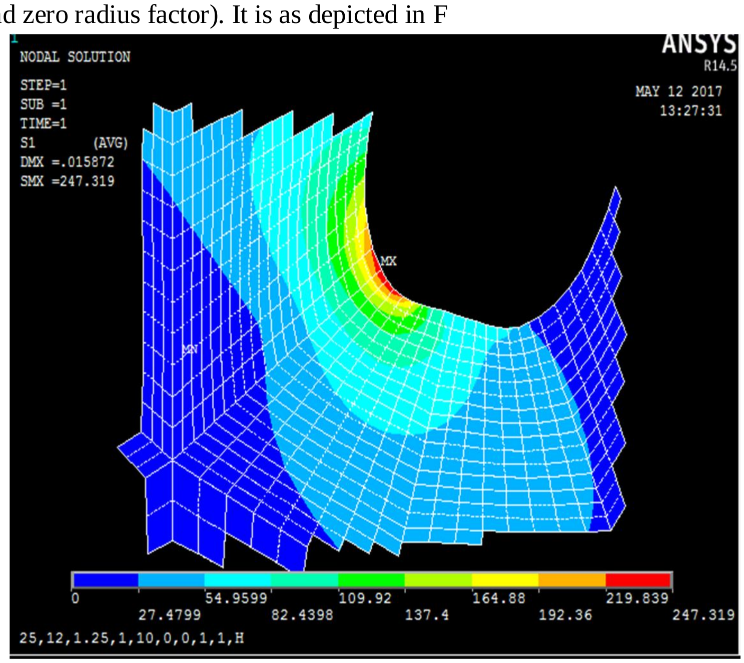

Fig.IV.1 Maximum Root fillet stress without relief hole

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B. Root Fillet Stress with SRF

The stress relief features of different geometry introduced at strategic locations will reduce the stress concentration on gear teeth. After the introduction of relief hole the maximum root fillet stress is reduced from 247.32 MPa to 227.19 MPa (reductions up to 8.12%), which will enhance the fatigue life of spur gear by redistributing the stress concentration in a smoother way.

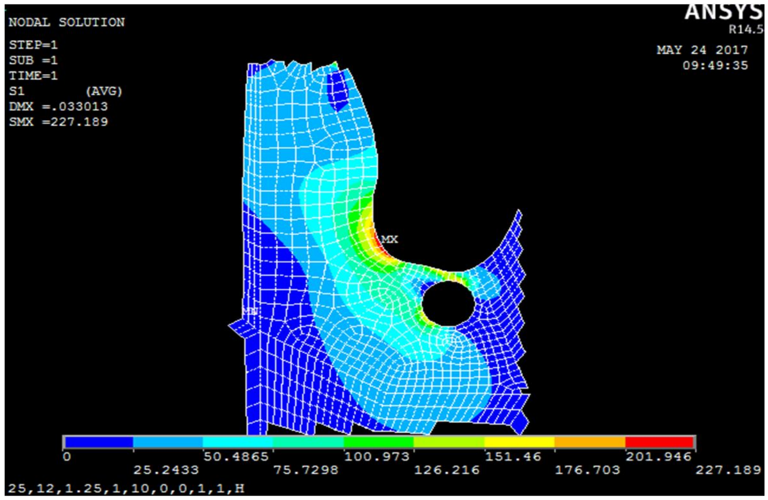

Fig. IV.2 Maximum Root fillet stress with relief hole

C. Fatigue Analysis of Spur Gear

Table IV.1 and Fig.IV.3 depicts Percentage increase in life for different pressure angle and number of teeth with profile shift factor -0.2 and zero factor of radius. Table IV.1

Pressure angle (α)	No. Teeth (Z)	Load cycles (N)	%increase in load cycles (N)
20.0	30	1.19E+06	1.09E+03
20.0	50	1.47E+06	1.37E+03
20.0	70	8.10E+05	7.10E+02
22.5	30	2.89E+07	2.88E+04
22.5	50	6.75E+06	6.65E+03
22.5	70	2.22E+06	2.12E+03
25.0	30	1.72E+08	1.72E+05
25.0	50	2.61E+07	2.60E+04
25.0	70	2.05E+06	1.95E+03

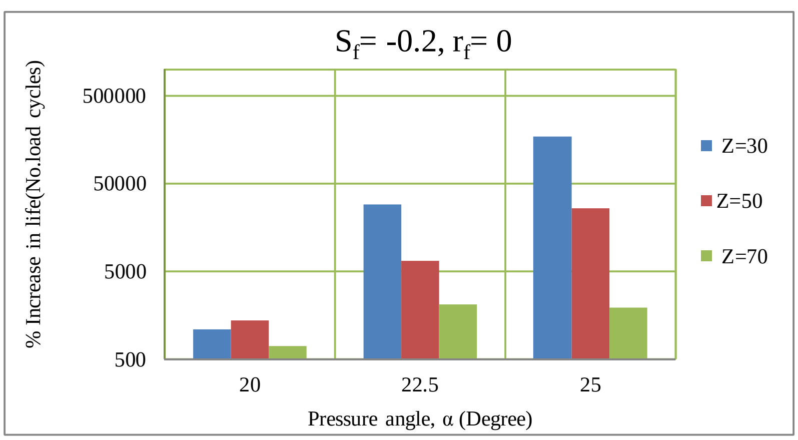

Figure IV.3

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From figure it is observed that percentage increase in life increases with increase in pressure angle for different number of gear teeth with profile shift factor -0.2 and zero factor of radius. The maximum percentage of increase in life is noticed for 30 numbers of teeth for pressure angle 25º, whose fatigue life is higher than gears with 50 and 70 numbers of teeth.

Table IV.2 and Fig.IV.4 depicts Percentage increase in life for different pressure angle and number of teeth with profile

Table IV.2shift factor -0.2 and zero factor of radius.

Pressure angle (α)	No. Teeth (Z)	Load cycles (N)	%increase in load cycles (N)
20.0	30	4.23E+06	4.13E+03
20.0	50	1.51E+06	1.41E+03
20.0	70	8.10E+05	7.10E+02
22.5	30	3.06E+07	3.05E+04
22.5	50	1.51E+07	1.50E+04
22.5	70	7.69E+05	6.69E+02
25.0	30	3.11E+08	3.10E+05
25.0	50	4.41E+07	4.40E+04
25.0	70	4.28E+07	4.27E+04

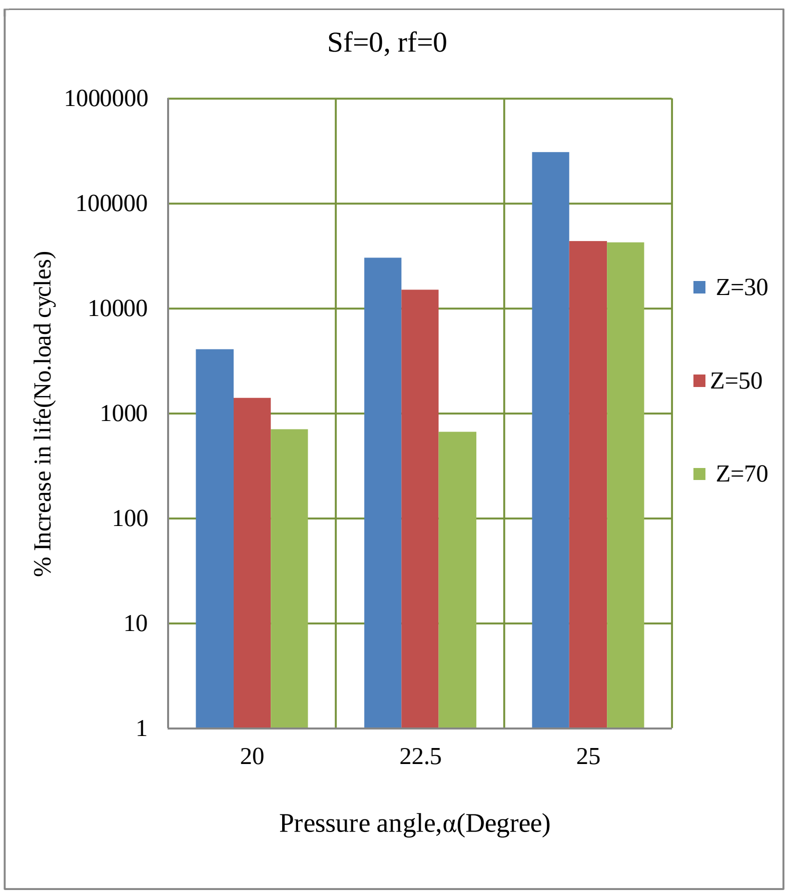

Figure IV.4 increase in percentage life of spur gear for profile shift factor 0 and 0

Table IV.3

Pressure angle (α)	No. Teeth (Z)	Load cycles (N)	%increase in load cycles (N)
20.0	30	2.57E+06	2.47E+03
20.0	50	1.27E+06	1.17E+03
20.0	70	8.10E+05	7.10E+02
22.5	30	3.54E+07	3.53E+04
22.5	50	1.41E+07	1.40E+04
22.5	70	1.32E+06	1.22E+03
25.0	30	2.78E+08	2.78E+05
25.0	50	3.87E+07	3.86E+04
25.0	70	7.43E+06	7.33E+03

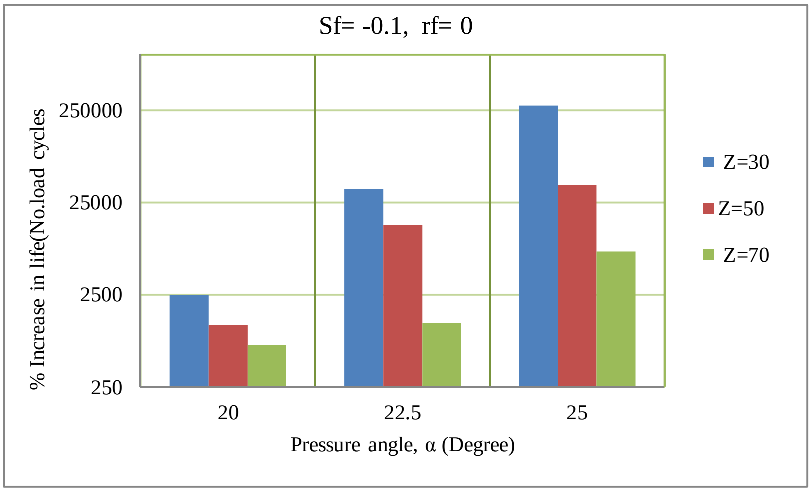

Figure IV.5 increase in percentage life of spur gear for profile shift factor -0.1 and 0

It is observed that percentage increase in life increases for different values of pressure angle and number of teeth. The increase in percentage of life for gear with 30 numbers of teeth is higher compared to gears with 50 and 70 numbers of teeths. It can be concluded that the fatigue life increases for spur gears with less number of teeth for constant factor of radius (i.e zero) and for change in profile shift factor (-0.2, -0.1 and 0) as pressure angle increases.

V. CONCLUSION AND SCOPE FOR FUTURE WORK

A. Conclusion

The study includes the estimation fatigue life of spur gear for different gear geometry subjected to 10 hp running at 1800 rpm. The ranges of gear and rack cutter parameters are as follows.

Pressure angle,	α=20º, 22.5º, 25º
Module	10
Number of teeth,	Z=30, 50, 70
Profile shift factor,	S_f = -0.2, -0.1, 0
Tool tip radius factor,	r_f = 0, 0.2, 0.25

The fatigue life estimated for gear with circular SRF found to be greater than that of fatigue life of gear without SRF. The reason behind the increase in load cycles is the stress relieved at tooth root when relief feature is introduced in gear.
Based on the analysis carried out and the results presented in results and discussion chapter the following conclusions are arrived.

1) The fatigue life of spur gear increases with increase in pressure angle with change in profile shift factor for constant factor of radius for gears with less number of teeth.
2) The increase in life ranges from 7.7×10^5 load cycle to 5.80×10^{10} load cycle. It is equivalent to 7.12 to 537037 hours of working life of gear.

B. Scope for Future Work

In the present work the root fillet stress reduction and fatigue life estimation of spur gear has been studied.

1) The present study can be extended to estimate the fatigue life of spur gear by introducing different stress relief features like elliptical and aero fin holes etc.
2) The study can extended to other type of gears like helical, bevel gears.
3) The analysis carried out may be experimentally verified

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