

# REDUCTION OF ROOT FILLET STRESS BY ALTERNATIVE ROOT FILLET PROFILE

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## Abstract

While generating the working profile (involute) of a spur gear using rack cutter, the root fillet curve is generated, automatically which is a trochoid. The root fillet obtained thus is not necessarily an optimum profile in context to the bending stress induced during its operation. This work investigates the stress at the gear tooth profile by replacing the conventional trochoid fillet by polynomial curves. The circular root fillet profile is constructed by drawing an arc tangent to working profiles and root circle and this arc is taken as reference root fillet to generate alternative root fillet profile. The arc is 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. This results presented here are based on two dimensional finite element analysis (FEA).

**Keywords:** Spur gear, Bending stress, Root fillet profile, FEA

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## 1. INTRODUCTION

One of the primary causes of gear tooth failure is the presence of large tensile stresses in the root fillet of loaded gear tooth. These stresses reduce the overall gear life and can result in catastrophic tooth failure under peak load conditions. Many attempts have been made by earlier investigators to relate the tooth failure and the tensile stresses observed in loaded gear, and found that maximum principle stress is the key factor, which governs the fatigue life of the spur gear. A small reduction in maximum principle stresses leads to increase in the fatigue life of the gears considerable. Therefore it is important to find out the method of reducing maximum principle stress in the gear there by increasing the life of gears. Progressives' improvements in gear design have taken place during the last few decades. Most of them are attributed to the use of material with improved strength, hardening the surfaces selectively with heat treatment and carburization, and shot peening to improve the surface finish. Many efforts such as altering the pressure angle, using the asymmetric teeth, introducing stress relief feature(SRF)[1] and using the gear with high contact ratio have been made to improve the durability and strength of the gear. Application of Stress relief feature (SRF) to reduce the stress concentration has limitation as the stress field is highly sensitive to location and size of the SRF. If these parameters are not well controlled insertion of SRF may affect adversely.

There are two general approaches to reduce bending stress for the given tooth size. One of them is to alter the generating cutter tooth tip-the most common application of this approach is to use a rack with full tip radius. Another approach is to alter the gear tooth fillet profile-the most common solution here is the circular (instead of trochoidal) fillet. Further development of both these approaches is based on a mathematical function-fitting technique where the cutter tip radius or the gear tooth trochoid fillet profile is replaced by a parabola, ellipse, and polynomial curve to reducing the bending stress. Bending stress reduction achieved by such fillet profile improvement is varied and greatly depends on the cutter or gear tooth parameters. The resulting tooth fillet profile must be checked for interference with the mating gear at various gear (and center distance) tolerance combinations.

In the literature, the majority of the proposed design aiming to substantial bending stress reduction in comparison to traditionally designed gears using Direct Gear Design fillet profile optimization technique [2, 3]. The idea of spur gear teeth with circular instead of the standard trochoidal root fillet is introduced and investigated numerically using BEM. The strength of these new teeth is studied in comparison with the standard design by discretizing the tooth boundary using isoperimetric Boundary Elements [4]. Fillets are usually the most critical regions in mechanical parts especially under fatigue loading, considering that an increase in the maximum stress level considerably shortens the fatigue life of a part. Therefore a systematic study is carried out to identify

alternative root fillet profile that reduces the root fillet stress for a given set of operating conditions.

### 2. ALTERNATIVE ROOT FILLET PROFILE

A spur gear tooth profile consist of working profile, root fillet profile and root circle if a rack cutter is used to generate the spur gear tooth profile (Ref. Fig-1).

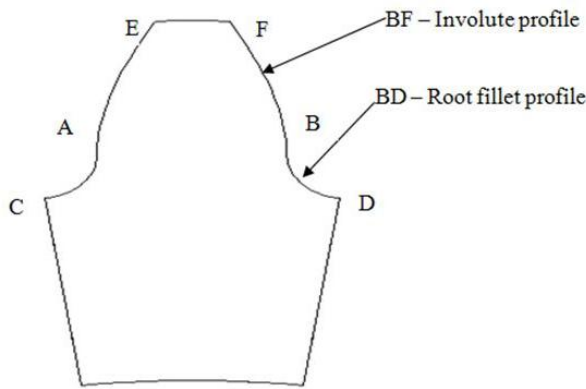


Fig -1: Spur gear tooth profile

The working profile generated thus is an involute and the root fillet profile is a trochoid and root circle is a circular arc. A circular arc tangent to root circle and adjacent involute profile is constructed as shown in Fig-2.

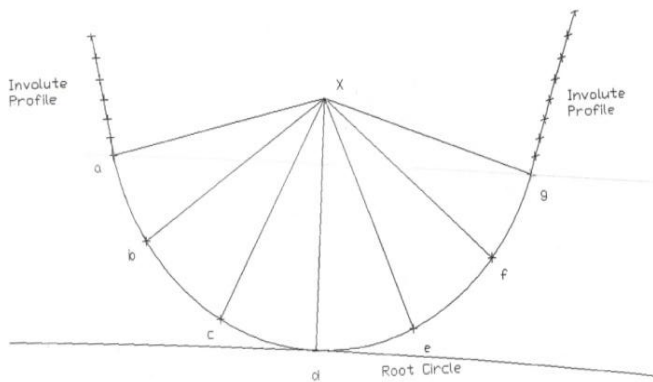


Fig -2: Construction of circular profile

This arc is divided into six equal segments. The alternative root fillet profile is constructed by a spline passing through the set of points obtained as follows. The end points on the circular arc fixed and the intermediate points are displaced along the corresponding radial lines. The middle point (d) is given a displacement along the radial in the multiples of 0.05 times the module and the other points are displaced with the linear variation along the corresponding radial lines (Ref. Fig-3). The coordinates of these points are used to construct the alternative root fillet profiles.

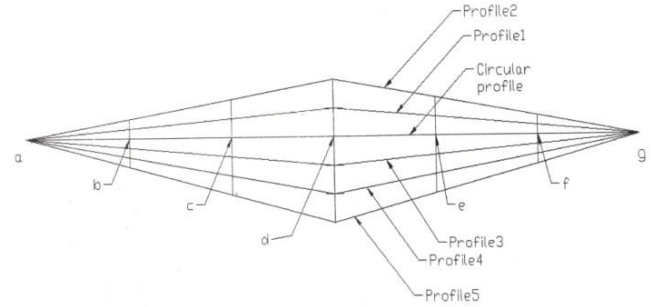


Fig -3: Linear variation of points on circular profile

In all three cases are considered for analysis. In case one number teeth and module are 40 and 10 respectively; in case two number teeth and module are 45 and 10 respectively and in case three number teeth and module are 30 and 6 respectively. In each case seven different root fillet profiles are used i.e. each case consist of seven gear geometries. Out of these seven profiles one is the circular arc and the other is trochoid and remaining are the new proposed root fillet profiles. The coordinates of the points used to construct the root fillet profile are given in Table 1 and 2.

Table -1: Coordinates of alternative root fillet profile

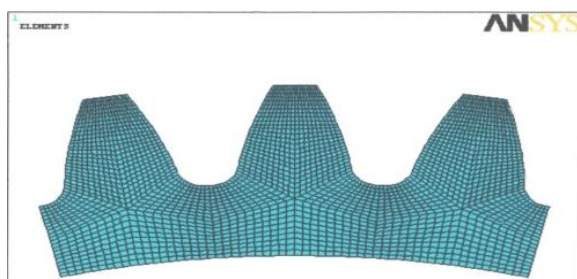
Case	Profile-1		Profile-2	
	X	Y	X	Y
-1 Case (Z=40, m=10)	9.9	191.2	9.9	191.2
	10.8	189.5	10.9	189.5
	12.6	188.0	12.7	188.2
	14.8	187.4	14.8	187.9
	17.0	187.6	16.9	187.9
	19.0	188.8	18.9	188.9
	20.1	190.4	20.1	190.4
-2 Case (Z=45, m=10)	10.1	216.0	10.1	216.0
	11.2	214.1	11.3	214.2
	12.9	212.9	13.0	213.2
	14.9	212.5	14.9	213.0
	16.9	213.0	16.8	213.0
	18.7	214.0	18.6	214.0
	20.1	215.0	20.1	215.0
-3 Case (Z=30, m=6)	5.6	85.2	5.7	85.2
	6.2	83.8	6.3	83.8
	7.3	82.7	7.4	82.9
	8.7	82.3	8.7	82.6
	10.1	82.4	10.0	82.6
	11.4	83.2	11.3	83.3
	12.2	84.5	12.2	84.5

**Table -2:** Coordinates of alternative root fillet profile

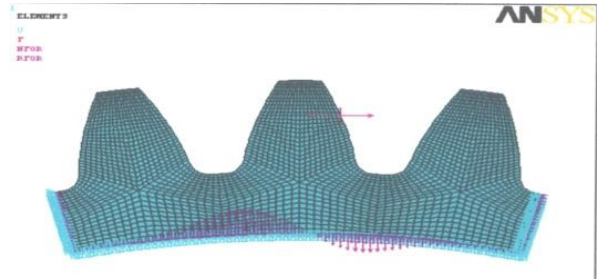
Case	Profile-3		Profile-4		Profile-5	
	X	Y	X	Y	X	Y
-1 Case (Z=40, m=10)	9.9	191.2	9.9	191.2	9.9	191.2
	10.5	189.3	10.4	189.2	10.2	189.1
	12.2	187.4	12.0	187.1	11.9	186.8
	14.7	186.4	14.6	185.9	14.6	185.4
	17.3	187.0	17.4	186.7	17.5	186.4
	19.2	188.6	19.4	188.5	19.5	188.4
	20.1	190.4	20.1	190.4	20.1	190.4
-2 Case (Z=45, m=10)	10.1	216.0	10.1	216.0	10.1	216.0
	10.9	213.9	10.8	213.8	10.6	213.7
	12.6	212.3	12.4	212.0	12.2	211.7
	14.8	211.5	14.8	211.0	14.7	210.5
	17.1	212.0	17.2	212.0	17.3	211.0
	19.0	213.0	19.1	213.0	19.2	213.0
	20.1	215.0	20.1	215.0	20.1	215.0
-3 Case (Z=30, m=6)	5.7	85.2	5.7	85.2	5.7	85.2
	6.0	83.7	5.9	83.6	5.8	83.6
	7.0	82.4	6.9	82.2	6.8	82.1
	8.6	81.7	8.6	81.5	8.5	81.2
	10.2	82.1	10.3	81.9	10.4	81.7
	11.5	83.1	11.6	83.0	11.6	82.9
	12.2	84.5	12.2	84.5	12.2	84.5

### 3. FINITE ELEMNT MODEL OF SPUR GEAR WITH ALTERNATIVE ROOT FILLET PROFILE

A program is developed in ANSYS Parametric Design Language (APDL) to automate the task of creation of model, meshing, applying boundary condition, choosing the appropriate density of the mesh depending on the stress gradient. A gear segment of three teeth is chosen as domain of finite element analysis. Fig-4 shows the geometric model of three teeth spur gear geometry. A point load of 200N is applied at highest point of single tooth contact (HPSTC). Fixed boundary conditions are applied along both the radial edges and arc of the rim of the spur gear as shown in Fig-5.



**Fig-1 :** Finite element Model of three teeth gear segment with profile -2 fillet

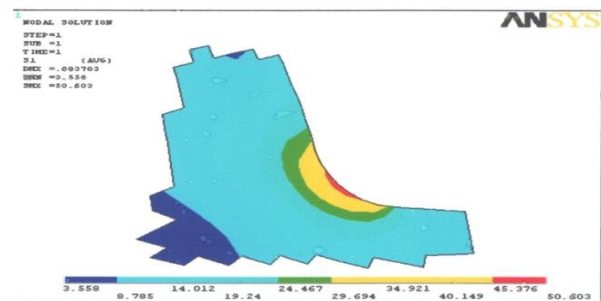


**Fig- 2 :** Finite element analysis of three teeth gear segment with profile -2 fillet subjected to load

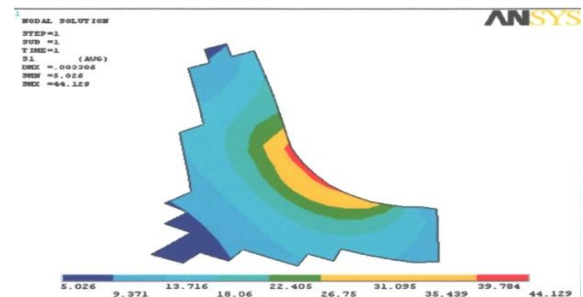
The gear segment is meshed with ANSYS eight node isoperimetric (PLANE82) element as shown in Fig. 5. Several mesh configuration of different mesh density are experimented to confirm the convergence of the finite element solutions. The maximum bending stress obtained from finite element analysis for each geometry is recorded.

### 4. RESULTS AND DISCUSSION

Fig-6 and Fig-7 depicts the distribution of stress in spur gear around critical point with trochoid and profile-2 respectively of case-1 as root fillet profile. The bending stress in spur gear for all the three cases studied using the alternative root fillet profiles are as shown in Fig-7. Root fillet profile two has resulted in less bending stress than the other alternative profiles (Ref. Table-3).



**Fig-3:** Principal stress distribution at tooth root fillet of trochoid

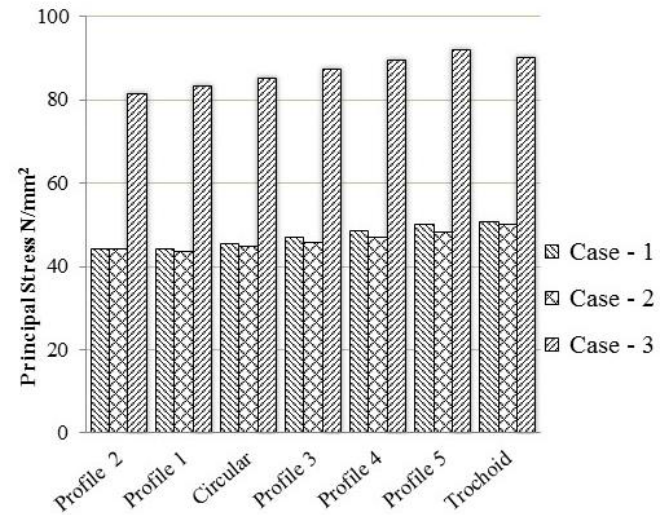


**Fig-4:** Principal stress distribution at tooth root fillet of profile -2

Maximum root fillet stress for all the three cases for seven different root fillets are given in Table-3 and are represented graphically in Chart -1.

**Table-3:** Comparison of root fillet Stress

Root fillet profile	Case -1		Case -2		Case -3	
	Root fillet Stress N/mm <sup>2</sup>	Percentage of reduction	Root fillet Stress N/mm <sup>2</sup>	Percentage of reduction	Root fillet Stress N/mm <sup>2</sup>	Percentage of reduction
Profile - 2	44.1	12.8	44.3	11.4	81.4	9.6
Profile - 1	44.3	12.5	43.5	13.0	83.3	7.5
Circular	45.5	10.0	44.7	10.7	85.2	5.3
Profile - 3	47.0	7.1	45.8	8.4	87.3	3.0
Profile - 4	48.5	4.1	47.0	6.1	89.6	0.5
Profile - 5	50.0	1.2	48.2	3.7	92.0	-2.2
Trochoid	50.60	Baseline	50.02	Baseline	89.98	Baseline



**Chart -1:** Stress Comparison of Profile

## 5. CONCLUSIONS

Based on the study the following conclusions have been made. The bending stress at the root fillet can be reduced by replacing the conventional trochoid with a polynomial curve. The profile gives improved results compared to trochoid fillet with stress reduction on 9% to 12%. The feasible design space lies above the circular profile, where there is reduction of stress compared to other profiles.

## ACKNOWLEDGEMENTS

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