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Investigation of Tooth Load Distribution along the Path of Contact in Altered Tooth-Sum Gears

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ABSTRAC: *The various needs of power and motion transmission in drives are undoubtedly fulfilled by gears. Satisfying the needs required for efficient and effective transmission depends on the tooth geometry. Hence, gear design involves a detail study of the tooth geometry as it determines various performance aspects regarding to load carrying capacity, wear characteristics, efficiency and noise. Among them the load carrying capacity is a fundamental requisite which depends on the bending strength calculated using Lewis equation which was formulated one hundred years ago. Most often, the tooth geometry of standard gears fail to meet certain needs, hence it is modified for better performance. The most common way of modifying the tooth geometry is by profile shift by using S-gearing, such profile shifting of gears influence the performance. As an alternative to S-gearing, it is proposed to modify the tooth geometry by altering the tooth-sum of a gear pair when center distance and module are specified. This involves increase or decrease of tooth-sum with eventual negative or positive profile shift respectively. With such alteration the gears are found to have different tooth geometry with unique benefits that are studied. The amount of profile shift for altering the tooth-sum of a gear pair can be calculated by the established equations of involutometry and trigonometry. The load distribution along the path of contact of such altered tooth-sum gears is understood using load sharing diagram that indicates the pattern of loading along the path of contact. This study considers spur gears under static loading, it involves comparison and analysis of load distribution on the gear tooth along the path of contact for both standard as well as altered tooth-sum gears.*

Key words: *Altered tooth-sum, High contact ratio, Load distribution, Profile shift*

Abbreviation

STS-Standard tooth-sum
ATS-Altered tooth-sum
BS-Bending stress
HPSTC-Highest point of single tooth contact
BS-HPSTC- Bending stress for load at HPSTC
BS-Tip- Bending stress for load at tip
CR/□-Contact ratio
NCR-Normal contact ratio
HCR-High contact ratio
GR-Gear ratio

Nomenclature

Z_1/Z_2-Number of teeth on standard pinion/gear
Z_e -Number of teeth altered
Z_1'/Z_2'-Altered number of teeth on pinion/gear
Z_s/Z_s'- Standard tooth-sum /Altered tooth-sum
A,B1,B2,C,D2,D1 and E - Salient points of contact
SPA/WPA - Standard/Operating pressure angle
α/α_e - Standard/Operating pressure angle
X_e-Total profile shift
X_1/X_2 - profile shift coefficient on pinion/gear
ym-Tooth topping (mm)

I. Introduction

Gears are fundamental kinematic elements used worldwide in many applications. The design features built into the gears rule its operating characteristics. The power that gears can transmit depends on the maximum permissible tooth load during mesh. Modern industrial drives require gears that can transmit heavy power with still good performance, to achieve this requirement it is necessary to design gears in which low tooth stresses are induced. For increasing the load carrying capacity of gears several alternatives are used, most of which involves modification of tooth profile by altering the pressure angle, introducing profile correction, fillet optimization, tip modification, asymmetric tooth design and use of dual materials. The common practice of modifying the tooth geometry is to use different portions of involute for the gear tooth which is known as profile shift. Profile shift is used when smaller numbers of teeth have to be generated in order to overcome the problems of interference and undercutting. Such modifications are done by S-gearing which may be either S_o or $S_{\pm}$ type. Among them S_o gearing is widely used, $S_{\pm}$ gearing being in rare use. A converse to this is proposed in this study in which the tooth-sum of a gear pair operating between the specified center distance and module can be altered with eventual profile shifting and tooth topping. The amount of profile shift needed can be computed using established equations. In this method, when the tooth-sum in a gear pair of given module is altered, the size of the base circles is modified that redefines an operating pressure angle and the path of contact. Maintaining the tooth contact along this new path necessitates profile shift. The load distribution pattern in such a modified tooth along the path of contact will be different which is studied in sufficient detail. Such a study leads to better understanding of the bending strength of the gear tooth in order to determine its load carrying capacity. In engineering applications the consideration of induced stress is more important than the magnitude of the applied load. Hence induced bending stress at the root considering load acting at different locations along the path of mesh is investigated.

II. Literature Review

Understanding the effort of earlier researchers regarding to the load distribution, bending strength and contact ratio in gears helps this study in different ways. The practical advantage of profile shifting is in avoiding the tooth contact below the base circle or at the beginning of the involute profile. The amount of profile shift required, its calculation and use have been discussed in [1-2]. **Maag** [3] was the first to use the principle of generating involute tooth using rack type cutter, he was also first to generate the involute gear tooth having profile shift. **Buckingham** [4] suggests that load on the gear tooth should be considered as acting at the tip for computing the bending stress as this consideration takes care of any misalignments. Altering the tooth-sum and its effect on few gear parameters have been discussed in detail by **Gonsalvis** [5]. **Dr.Joseph Gonsalvis and Sachidananda. H.K** [6] has shown that the contact stresses for altered tooth-sum gears are much lower than standard tooth-sums gears. **Dr. Joseph Gonsalvis** and **H.R.Prakash** [7] report that minimum power loss is observed in altered tooth-sum gears so that power transmission can be maximized when negative teeth alterations are considered. **A.R.Rajesh et.al** [8] has studied the influence of altering the tooth-sum on bending stress by plotting the induced bending stress against profile shift co-efficient for different loading locations along the tooth profile. It is reported that the bending stress is reduced by 35.28% with negative teeth alteration having positive profile shift while the contact ratio is increased by 24% with positive teeth alteration having negative profile shift. **M.Rameshkumar et.al** [9] has performed load sharing analysis and comparison of NCR and HCR gears in terms of percentage load shared from root to tip of a gear tooth. Here, load distribution is plotted with respect to rotation angle for a single tooth from load at root to load at tip. The load sharing diagrams clearly show the point of maximum bending stress on the tooth profile, i.e., HPSTC. It is reported that the load carrying capacity of HCR gears is 18% more than NCR gears having same weight and volume for fixed module and center distance. **P.Marimuthu et.al** [10] has studied the influence of different gear parameters such as addendum height, tooth number and module on load sharing aspect followed by stress analysis. **Sabah M.J.Ali et.al** [11] have studied the effect of changing the contact ratio on stresses generated on meshing gear tooth for many cases of contact ratio between 1.6 and 2.0 to determine the location of the load on the meshing tooth. This study has revealed that high contact ratio results in lowest generated tooth stresses which depend on the value of direction and location of load applied on the involute tooth profile. **M.Rameshkumar et.al** [12] have tried to minimize the operating noise and vibration to reduce the weight with the view of improving the power-to-weight ratio for the case of 35-ton capacity military tracked vehicle's final drive that uses helical gears. The study is focused on replacing the NCR gears with HCR gears without any change in existing final drive assembly. By the analysis of load sharing percentage using finite element approach, it is observed that 25% less stresses are induced with HCR gearing. **A.R.Rajesh et.a**l.[13] have analytically studied the load sharing with emphasis to bending stress in altered tooth-sum gears.

III. Objectives

After a thorough review of available literature, the objectives of this study are identified as listed:

i. To introduce profile shifting by way of altering the tooth-sum in gear pair.
ii. To study the tooth profile of altered tooth-sum gears.
iii. To understand the load distribution along the path of contact in altered tooth-sum gears.
iv. To investigate the effects of altering the tooth-sum on tooth load distribution, root bending stress as well as contact ratio.

IV. Altered Tooth-Sum Design

Literature survey reveals that until recently there has been little information regarding introducing profile shift by altering the tooth-sum among the mating gears. Such studies are carried out by very few researchers. The sum of teeth of the mating gears of a gear pair is known as tooth-sum. For a given module and tooth-sum if profile shift is introduced on the gears its center distance changes, conversely for a given center distance if profile shift is introduced different tooth numbers can be accommodated for the same module, but such altered tooth-sum gears operate on a different pressure angle known as operating or working pressure angle. Hence this is a unique and promising approach to gear design in which the tooth-sum of a gear pair can be varied for a given standard center distance and module that necessitates profile shift. The tooth-sum may be increased which necessitates negative profile shift and vice-versa. Since the center distance is specified, altered tooth-sum gears are subjected to tooth topping in order to ensure a backlash-free contact.

When the tooth-sum of a standard gear pair is altered the following geometrical changes takes place:

i. Alteration in number of teeth of pinion or gear or both.
ii. Modifications in size of the base circle that alters the pressure line.
iii. Modification in pressure angle that introduces operating or working pressure angle.
iv. Modification in tooth dimensions regarding to tooth height and thickness along tooth profile.

The above changes also influence other geometrical aspects like length of active profile, radius of curvature of involute, location of pitch point etc., affecting load carrying capacity, contact strength, contact ratio etc. The size of the base circles of standard gear pair changes due to alteration in tooth-sum, while the center distance and module being standard. The common tangent to the altered base circles redefines the path of contact introducing an operating pressure angle α_e. This operating pressure angle will be larger or smaller than the standard pressure angle depending on whether it is negative teeth alteration or positive teeth alteration. The resulting operating pressure angle and the amount of total profile shift to be accommodated can be calculated by using the equations:

$$\alpha = cos^{-1}\left(\frac{Zs'\cos(\alpha)}{Zs}\right) \quad - (1)$$

$$\mathrm{Xe} = \frac{Zs'(\mathrm{inv}\ \alpha e - \mathrm{inv}\ \alpha)}{(2\tan\ \alpha)} \quad - (2)$$

A convenient and judicious distribution of this resulting profile shift inherits certain unique benefits to altered tooth-sum gearing. The benefits depend on how the geometry of the gear tooth is influenced by the teeth alteration.

Table. I - DETAILS OF ALTERED TOOTH-SUM 100 GEARS FOR GR 1:1
(For equal distribution of resulting profile shift, i.e., X1=X2)

Z_e	Z_s'	Z_1'x Z_2'	□$_{e,}$ (deg)	X_e	X_1	X_2	Contact ratio (□)	No. of Teeth pair in contact
- 4	96	48x48	25.564	2.277	1.139	1.139	1.26	1 and 2
- 3	97	48x49	24.286	1.659	0.829	0.829	1.40	1 and 2
- 2	98	49x49	22.942	1.072	0.536	0.536	1.52	1 and 2
-1	99	49x50	21.519	0.518	0.259	0.259	1.64	1 and 2
0	**100**	**50x50**	**20.000**	**0.000**	**0.000**	**0.000**	**1.75**	**1 and 2**
+1	101	50x51	18.361	-0.481	-0.24	-0.24	1.84	1 and 2
+2	102	51x51	16.567	-0.920	-0.46	-0.46	1.93	1 and 2
+3	<u>103</u>	51x52	14.560	-1.314	-0.657	-0.657	<u>2.01</u>	<u>2 and 3</u>
+4	<u>104</u>	52x52	12.237	-1.657	-0.828	-0.828	<u>2.08</u>	<u>2 and 3</u>
+5	<u>105</u>	52x53	9.363	-1.938	-0.969	-0.969	<u>2.17</u>	<u>2 and 3</u>

The details of different altered tooth-sums and its design parameters for a gear pair of tooth-sum 100 having module 2 mm are shown in Table I. Figures in bold represents standard gearing. It can be seen that for the standard center distance 100 mm it is possible to accommodate a maximum negative teeth alteration of -4 resulting in tooth-sum 96 and a maximum positive teeth alteration of +5 resulting in tooth-sum 105. Teeth alteration beyond these limits lead to geometrical irregularities that are not permissible by design. Hence, only permitted design conditions regarding to undercutting, top land thickness, contact ratio and location of pitch point are considered to identify an operable domain. For each tooth altered in a gear pair the gears will receive profile shift accordingly. The tooth-sum resulting in HCR gearing is underlined.

V. Salient Points of Gear Tooth Contact

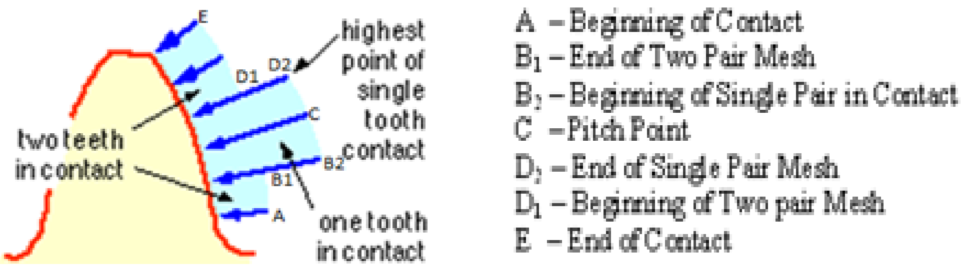


Fig. 1 Salient points of mesh along tooth profile.

As gear tooth contact begins and progresses, the salient points of mesh A, B1, B2, C, D2, D and E along the tooth profile between the points of engagement and disengagement is shown in Fig.1. The load distribution on the gear tooth changes only at these salient points. Among these salient points D2 representing HPSTC loading and E representing tip loading are important from point of design, hence only those points are considered in this study.

VI. Load Distribution Along The Length of Contact

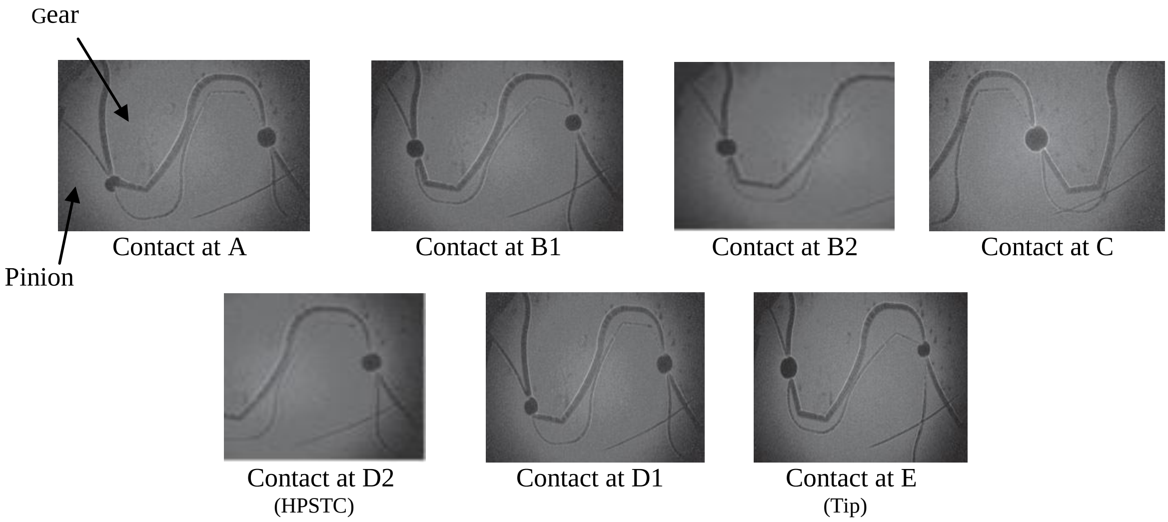
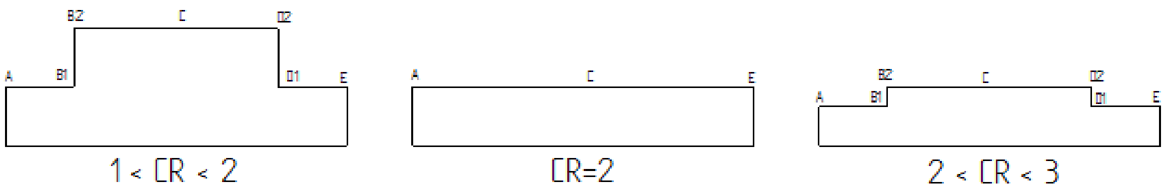


Fig. 2 Contact configuration showing the salient points of contact.

Fig.2 shows the contact configuration at different load locations during the meshing cycle that varies along the path of contact. During such variation the tooth contact shifts from one pair to two pair contact and vice-versa. The load shared along the path of contact depends on the contact ratio of the gearing. As the contact radius changes both the bending moment and bending stress are affected.



(a) Contact ratio less than two (b) Contact ratio equal to two (c) Contact ratio greater that two

Fig. 3- Basic load sharing along the length of contact.

Fig.3 shows the basic tooth load shared along the length of contact. A tangential load of 98.1 N acting on the pitch circle of the gear tooth will result in a normal tooth load of 104.3 N for 20 deg pressure angle gears. When the contact ratio is less than two, the tooth load on the gear tooth is ½ the full load (two pair of teeth) for some time of engagement and full load (one pair of teeth) for the remaining time of engagement as seen in Fig. 3(a).

As such, for a normal tooth load of 104.3 N, full load of 104.3 N (one pair of teeth) will act at HPSTC and a distributed load of 52.15 N (two pair of teeth) will act at the tip. When the contact ratio is exactly two which is a very rare or theoretical condition, the load on the gear tooth never exceeds ½ the full load (two pair of teeth) throughout the meshing cycle at any point of time as in Fig. 3(b). As such, for a normal tooth load of 104.3 N, ½ the full load, i.e., 52.15 N (two pair of teeth) will act both at HPSTC as well as at the tip. Similarly, when the contact ratio is greater than two, the tooth load on the gear tooth is 1/3rd the full load (shared by three pair of teeth) for some time of engagement and ½ the full load (shared by two pair of teeth) for the remaining time of engagement as in Fig. 3(c). As such, for a normal tooth load is 104.3 N, a distributed load of 52.15 N (two pair of teeth) will act at HPSTC and 34.76 N (three pair of teeth) will act at the tip. This means that the gear tooth will never take up the full load during the entire meshing cycle. Such configuration in which a minimum of two pairs of teeth will always be in mesh is known as High contact ratio (HCR) gears. In such HCR gearing the normal tooth load is reduced by 50% for HPSTC loading and 33.34% for tip loading.

VII. Contact Ratio

Contact ratio of a gear pair in mesh is the ratio of the length of the path of contact to the base pitch. By knowing the contact ratio of the gearing the load distribution on the gear tooth along its path of contact can be studied. The load shared along the path of contact varies as illustrated in Fig.1. The contact ratio of a standard gear pair is affected only when the tooth profile is modified. In altered tooth-sum design, both profile shift and tooth topping occurs, these modifications contribute to significant changes in load sharing pattern.

Fig.4 shows the variation of contact ratio against profile shift co-efficient for different teeth altered over a tooth-sum 100 allowing the profile shift X_1 on pinion and $X_2=X_e-X_1$ on the mating gear. From the illustration it is seen that the contact ratio increases with increase in teeth alteration Z_e upto certain limit beyond which it again decreases, this means that there is an optimum profile shift coefficient for each altered tooth-sum gearing leading to highest contact ratio. For any altered tooth-sum gears having GR 1:1 the value of contact ratio is observed to be maximum when the resulting total profile shift is equally distributed between the mating gears. Under such distribution the length of approach and length of recess will be equal. From altered tooth-sum design HCR gearing can be achieved which is not possible with standard gears for the given 20 degree pressure angle.

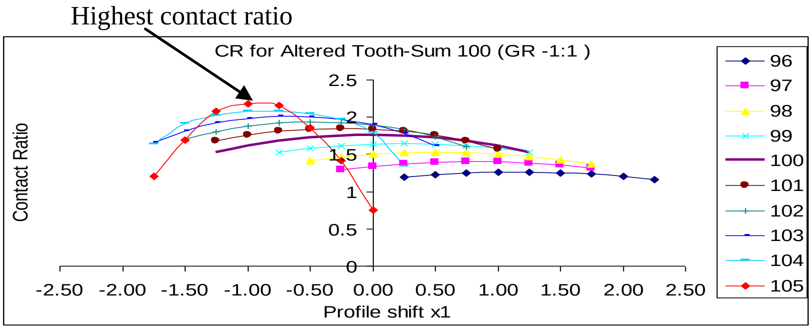


Fig. 4 Contact ratio vs. X_1

VIII. Load Sharing Diagrams

Alteration in tooth-sum alters the tooth geometry due to change in the teeth number, working pressure angle and profile shift. Due to these changes the load shared along the tooth profile is affected, understanding of which necessitates the study of the following cases:

A. Standard gears.
B. Standard gears with change in teeth number.
C. Standard gears with different pressure angle.
D. Profile shifted gears.
E. Altered tooth-sum gears.

Load sharing pattern is drawn on comparative basis for any three considerations of tooth-sum, pressure angle and profile shift that can be analyzed at a time. Such comparison between the standard and altered tooth-sum gears lead to better understanding and analysis of bending strength, contact ratio and load shared along the path of contact in altered tooth-sum gears. A load sharing diagram shows the bending stress on the ordinate and length of contact along the abscissa. The contact configuration affects the load sharing pattern influencing the bending stress which depends on whether it is NCR (CR<2) or HCR (CR>2) gearing depending on the length of contact. In the load sharing diagrams illustrated ahead, the notations and values in the legend clearly indicates the details of various parameters considered in the design.

A. Standard gears

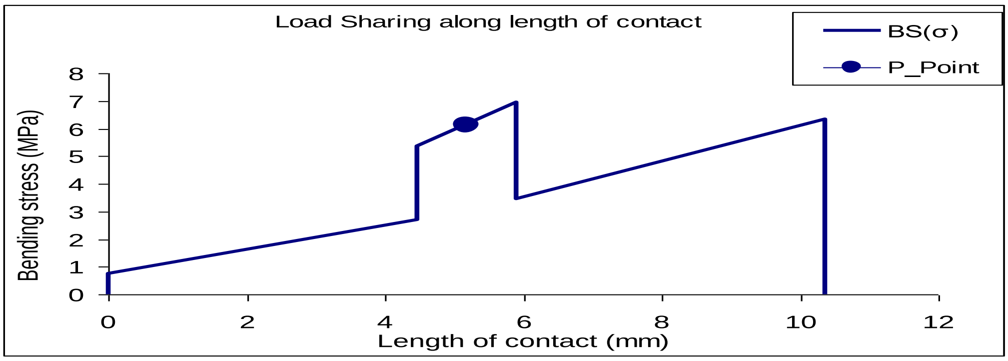


Fig. 5-Load sharing along length of contact for STS 100

Fig. 5 shows the load sharing diagram along the salient points of contact in congruence with Fig.1. As the contact establishes at A and progresses the contact radius increases, accordingly the bending stress. The contact begins at A and ends at E both having double pair contacts. In the middle of contact journey the gear tooth encounters single pair mesh as the contact shifts from double pair to single pair situation (B1 to B2) and again from single pair to double pair situation (D2 to D1). This results in variation of tooth load shared by the gear pair in mesh, as such the bending stress varies along the length of contact. At these transition points from double pair to single pair contact or otherwise the bending stress increases or decreases suddenly and repeatedly for every rotation on every tooth, the bending stress being practically maximum at D2. This point where maximum stress is encountered is known as HPSTC (Highest point of single tooth contact). From the illustration it can be seen that for standard gears with gear ratio 1:1 the pitch point is at middle having length of approach equal to length of recess.

B. Standard gears with change in teeth number

For a standard tooth-sum of given GR, a marginal increase or decrease, say ±4 teeth on the gear pair alters the tooth geometry marginally. As such, considering the pinion it is seen in Fig. 6 that the bending stresses and contact ratio is also affected marginally. The bending stress is marginally higher for decreased teeth number and vice-versa, similarly the contact ratio is marginally lower for decreased teeth number and vice-versa. This marginal effect prevails only for GR 1:1, when the GR changes for given tooth-sum the teeth-number on pinion changes substantially, hence its effect on bending stress and contact ratio will be more [13].

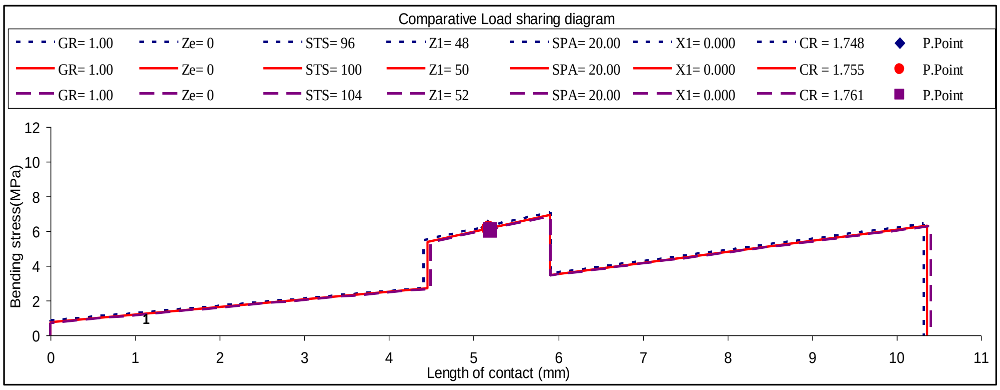


Fig. 6-Load sharing diagram for STS 100, different tooth-sum.

By observing the length of contact in load sharing diagram, it can be said that the contact ratio is least affected by marginal change in teeth number for a given GR.

C. Standard gears with different pressure angle

The pressure angle of a gear being one of the significant parameter, when changed alone alters the shape of the gear tooth to a greater extent compared to case (B) above. The load sharing pattern shown in Fig. 7 considers three pressure angles 14.5 deg (short dashed blue line), 20 deg (continuous red line) and 25 deg (long dashed purple line). It is seen that the bending stress is higher for lower pressure angle and vice-versa.

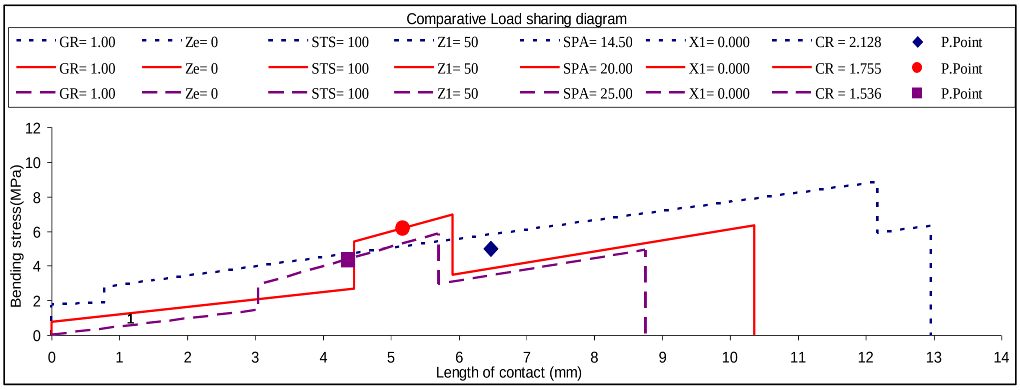


Fig. 7- Load sharing diagram for STS 100, different pressure angle.

By observing the length of contact in the load sharing diagram, it can be said that the contact ratio increases greatly for lower pressure angle and vice-versa, hence the contact ratio is greatly influenced by pressure angle. A lower pressure angle of 14.5 deg leads to HCR gearing with contact ratio 2.128 as shown in the legend.

D.Profile shifted gears

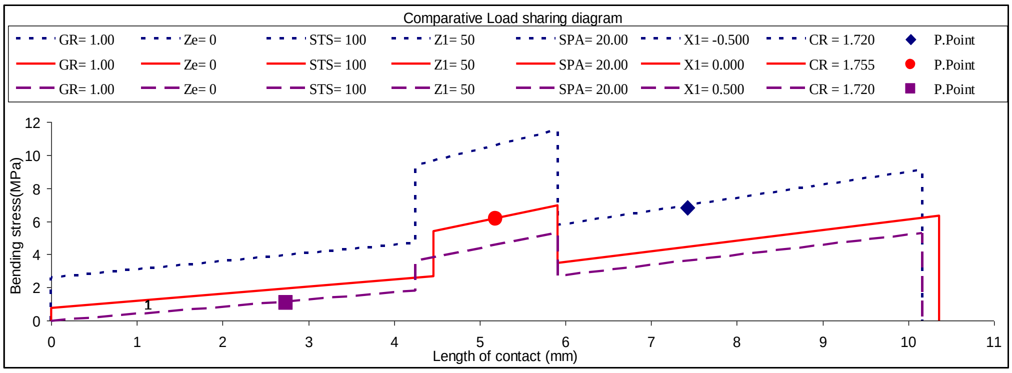


Fig. 8 -Load sharing diagram for STS 100 with profile shift

As the tooth geometry changes by So gearing both bending stress and contact ratio are affected. The bending stress decreases for positive shift due to increased tooth thickness and vice-versa, while the length of contact decreases reducing the contact ratio. This is due to decreased length of contact. Fig.8 illustrates that the pitch point gets located either towards A or E depending on whether the profile shift is positive or negative. In S_o gearing the length of approach will not be equal to length of recess, for positive correction the length of approach will be shorter than the length of recess and vice-versa. For both positive and negative shifts the length of contact reduces, hence the contact ratio decreases due to profile shifting. The maximum contact ratio is achieved with standard gears, for profile shifted gears, whether positive or negative shift, the contact ratio decreases. For equal amount of negative and positive corrections i.e., X1= -0.5 and X1=+0.5 the deviation in bending stress will be unequal and opposite, this being more for negative correction.

By observing the length of contact in the load sharing diagram, it can be said that the contact ratio slightly decreases for both positive and negative profile corrected gears. Hence the contact ratio decreases due to profile shift.

E. Altered tooth-sum gears

Fig. 9 shows the load sharing pattern from first point of contact A to last point of contact E for altered tooth-sum 100 gears. It is seen that reduced equal bending stress occurs with X1=1.139 for a negatively altered tooth-sum 96 and maximum contact ratio occurs with X1=-0.969 for a positively altered tooth-sum 105. The length of contact decreases greatly for negative teeth alteration due to less tooth topping and higher operating pressure angle resulting in NCR gearing. The length of contact increases greatly for positive teeth alteration due to more tooth topping and lower operating pressure angle, this resulting in HCR gearing. The length of single pair contact for altered tooth-sum 96 gearing is more than the length of single pair contact for standard tooth-sum 100, total length of contact being very less. Hence the contact ratio for negatively altered gear pair of tooth-sum 96 is 1.266 which is less than the contact ratio 1.755 of standard tooth-sum 100. On the other side, for positively altered gear pair of tooth-sum 105 the teeth engagement shifts from double pair to triple pair contact.

Hence it results in HCR gears having contact ratio of 2.177 which is greater than the contact ratio 1.755 of standard tooth-sum 100. Under such circumstances the length of contact becomes more than twice the base pitch, which would otherwise result in NCR gearing encountering 100% greater levels of bending stress at HPSTC and 50% greater levels at tip. This shows that altered tooth-sum gearing can be used to obtain stronger gears having lower bending stress or higher contact ratio gears for quiet running.

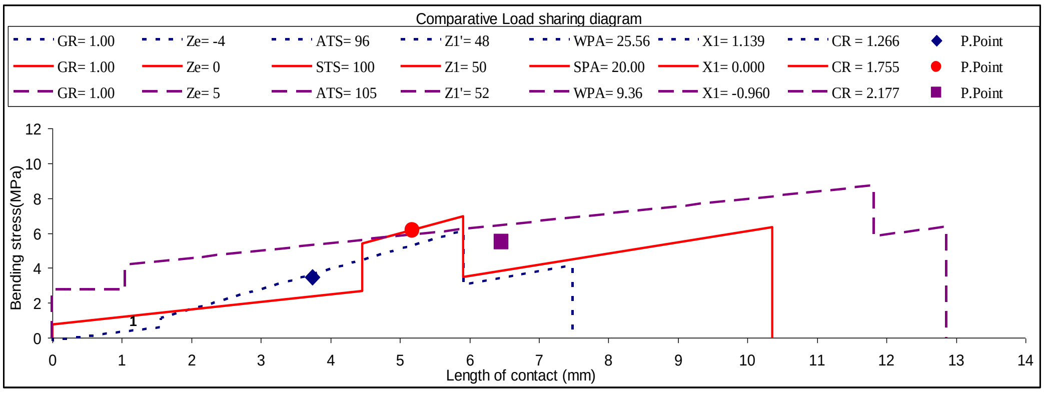


Fig. 9- Load sharing diagram for Altered tooth-sum 100 gearing

IX. Results And Discussion

Table II. RESULTS OF ATS 100 GEARS, GR 1:1

Negative tooth-sum 96	**For Minimum Bending stress (BS) condition**	Zs= 100(50x50) Ze= -4 Zs'= 96(48x48) X_e= 2.277 X_1= 1.139 X_2= 1.138			Normal Tooth load acting at tip (104.3 N)	
	Parameter	BS-HPSTC (MPa)	BS-Tip (MPa)	CR	Load at HPSTC (N)	Load at Tip (N)
	Standard gears	6.94	12.66	1.755	104.3	52.15
	ATS gears	6.108	8.193	1.266	104.3	52.15
	% change	-12% (decrease)	-35.28% (decrease)	-27.86% (decrease)	0% (No change)	0% (No change)
Positive tooth-sum 105	**For Highest Contact ratio (CR) condition**	Zs= 100(50x50) Ze= +5 Zs'= 105(52x53) X_e= -1.938 X_1= -0.969 X_2= -0.969			Normal Tooth load acting at tip (104.3 N)	
	Parameter	BS-HPSTC (MPa)	BS-Tip (MPa)	CR	Load at HPSTC (N)	Load at Tip (N)
	Standard gears	6.94	12.66	1.755	104.3	52.15
	ATS gears	8.768	19.218	2.177	52.15	34.76
	% change	+26.34% (increase)	+51.80% (increase)	+24.05% (increase)	-50% (decrease)	-33.34% (decrease)

Table.II shows the analytical results for involute spur gears of GR 1:1, tooth-sum 100, 2 mm module, 20 deg pressure angle and 10 mm face width considering a static load of 9.81 N/mm of face width. Though many combinations of altered tooth-sum and profile shift are possible, design conditions such as undercutting, minimum top land thickness, minimum contact ratio and location of pitch point are taken care to identify an operable domain. For cases (B), (C) and (D) of the previous section, the profile modification leads to changes in tooth geometry due to change in teeth number, pressure angle and profile shift respectively taken individually. But, in altered tooth-sum gearing all these changes takes place along with tooth topping that makes this a unique design. In this study, the altered tooth-sum design is understood and implemented for a gear pair of tooth-sum 100 having 50 teeth on each of the pinion and gear. Based on the investigation, it is identified that negative teeth alteration having positive profile shift reduces the bending stress and positive teeth alteration having negative profile shift increases the contact ratio. Some positive tooth-sums even lead to HCR gearing having a better load distribution.

From this novel approach it is understood that altering the tooth-sum alters the tooth geometry in a unique way. Hence when positively altered tooth-sum gears are considered a reduction in the basic loading to the tune of 50% for HPSTC and 33.34% for tip load locations can be achieved. This results in a HCR of 2.177 which is 24% greater than the CR of standard gears that lead to a better load distribution and quiet running. Similarly, when negatively altered tooth-sum gears are considered a reduction in bending stress of up to 12% for HPSTC and 35.28% for tip load condition is achieved compared to standard gears, this leads to a stronger gear tooth with high load carrying capacity.

X. Conclusion

Better load sharing in gear tooth using altered tooth-sum design is possible. The tooth numbers of a standard gear pair operating between a standard center distance and module can be varied with negative or positive teeth alterations leading to a reduced tooth bending stress or increased contact ratio respectively. To enhance the bending load capacity, altered tooth-sum gearing that operates on a different pressure angle while in mesh was considered. Spur gears of module 2 mm having tooth-sum 100 was altered to have decreased and increased tooth-sum ranging from 96 teeth to 105 teeth with operating centre distance 100 mm and pressure angle 20^{o} to study the effect on load distribution, bending stress and contact ratio. With judicious selection of teeth alteration and distribution of resulting profile shift, it is possible to design gears to have a lower basic load on the gear tooth, lower tooth bending stresses for better load carrying capacity or higher contact ratio for quiet operation. Positive tooth-sum gearing yields a better load distribution along the path of contact as it has increased contact ratio, higher positive tooth-sums leading to HCR gearing.

Considering the various needs of gearing, the pattern of load distribution in altered tooth-sum design ensures

i. High load carrying capacity.
ii. Quiet operation.
iii. Reduced load on shaft and bearings.
iv. Longer life.
v. Reduced cost.
vi. No structural changes in gear box.

The identified benefits can be achieved without resorting to any structural changes in the gear units, additionally these gears do not need separate or additional manufacturing or tooling justifying its practicability.

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