Effect of Addendum Modification on Root Stress of Spur Gear

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Abstract*- In order to accomplish high load carrying capacity with reduced weight of gear drives but with increased strength in gear transmission, gear tooth stress analysis, tooth modifications and design of gear drives are becoming major research area.For failure of gear bending stress at root is one of the most dominant reason while gears are operating. The main objective of this research is to study the effect of different addendum modification coefficients on root stresses of spur gear. For this purpose first we will select proper addendum modification coefficients by considering undercutting and peaking(pointing of tooth) limitation. With these coefficients root stresses have been calculated by analytical method. From this study we have tried to find the addendum modification coefficients that will produce minimum root stresses. This study also gives information about how root stresses are varying with selecting different gear pair for same module, gear ratio. i.e. So, Sn, S gearing.*

Keywords- spur gear,Addendum modification coefficients, root stress, bending stress.

I. INTRODUCTION

The increasing demand for high tooth strength and high load carrying capacity of gears leads to various methods of improvements. One of the major method available till now is "Profile Shift". In gear technology it is known as "Addendum Modification". The amount by which the addendum is increased or decreased is known as "Addendum Modification".

It is expressed as a product of module (m) and a non-dimensional factor(X). This non-dimensional factor (X) is known as "Addendum Modification Coefficient" or "Correction Factor'.This product X.m is in mm. When positive correction(i.e.+X.m) is applied to the gear, it increases the addendum of the gear. And When negative correction(-X.m) is applied , it decreases the addendum of gear. Depending on the distribution of Addendum modification for pinion and gear, there are three types of gearing A.S_nGearing(X_1=X_2=0) B.S_0 Gearing(X_1=-X_2) C. S Gearing(X_1+X_2=+Ve or X_1+X_2=-Ve).

The aim of addendum modification is to avoid interference. Previously various methods used to avoid interference were:

- Undercutting at the root.
- Making the mating gear tooth stub.
- Using a minimum number of teeth in a gear for a certain pressure angle.

But undercutting weakens the tooth strength severely and there may be the situation where a smaller number of teeth in a gear is to be adopted. But addendum modification avoids all these difficulties. It is also known that profile-shifted gears as compared to standard gears, offer a lot of advantages. The load carrying capacity of the gears can be greatly improved without any appreciable change in gear dimensions by adopting addendum modification.

Now-a-days profile shifted gears are more often due to its reduced vibration and reduced noise property. All these facilities can be achieved without using any special cutters.

Spur gears with a pressure angle of 20 degrees are usually used as power transmitting gears. But the need for higher load carrying capacity gives way for the selection of higher pressure angles. Gears with higher pressure angles are often used in aircraft applications.

Root stress measures the strength of the gear tooth. So if root stress is more, the gear tooth is weaken and when root stress is less, the gear tooth becomes stronger. In this project work the effects of addendum modification on root stress are investigated. The effects on root stress are investigated by both increasing and decreasing the height of addendum. In order to calculate the root stress at the root fillet of the gear tooth, a formula is adopted given by IS standard.

1.Gear Parameters for Calculation of Root stresses

Table1.Gear parameters

Module	5mm
Pinion diameter	100mm
Gear diameter	200mm
Pinion Teeth Z1	20
Gear Teeth Z2	40
Addendum	5mm
Dedendum	6.25mm
Tangential force	1884.47N
Face width	50mm
Input speed	3800 RPM
Output speed	1900 RPM

2.Root Stress Calculation Formulae:

Root stresses can be found out by Lewis bending equation used for gears, which is given as below:

$\sigma_f = \sigma_{fo} K_A K_V K_{FB} K_{F\alpha}$ ....(1)

σ_{fo}-Nominal tooth root stress
K_A-Application factor
K_V-Dynamic factor
K_{FB}-Face load factor
$K_{F\alpha}$-Transverse load factor

$\sigma_{fo} = \frac{Ft}{B*M} * Y_F . Y_s\, Y_\beta . Y_B\, Y_{DT}$....(2)

Y_F-Form factor
Y_S-Stress concentration factor
Y_β-Helix angle factor
Y_B-Rim thickness factor
Y_{DT}-Deep tooth factor

In above equation of bending stress at root of gear blank, the factor Kv is varying with addendum modification coefficients. The factors $K_{A,}$ $K_{FB,}$ $K_{F\alpha}$ are used from IS standards. To calculate Kv, we have to select proper Addendum Modification coefficient for selected gear pair.

3.Addendum modification coefficients selection range:

X1-addendum coefficient on pinion
X2-addendum coefficient on gear
Z1-Pinion teeth
Z2-Gear teeth
ΣZv- Z1+Z2

Recommended limits for ΣX=X1+X2:
Upper limit:
For 20< ΣZv ΣX=1.0

Lower limit:
For 20≤ ΣZv ≤ 60 ΣX=0.025(60-ΣZv)
For 60< ΣZv ΣX=0.0
Where, ΣZv= ΣZ(for spur gear) =Z1+Z2

Distribution of coefficients X1 and X2:

$X1 = ƛ * \frac{Z2-Z1}{Z2+Z1} + X * \frac{Z1}{Z2+Z1}$ ….(3)

Limit for X:
Upper limit
For 6<Z, X=0.6

Lower limit
For 6<Z<50 X=0.025*(30-Z)
For 50<Z, X=0.5

Limit for ƛ:
0.5<ƛ<0.75 for speed reducing gear
0<ƛ<0.5 for speed increasing gear

Coefficient X2 can be calculated as:
X2=ΣX - X1.

In order to study the effect of different addendum modification coefficients on gear and pinion, we need to distribute the sum as per above limitations. So calculations have been performed as per following table and root stresses are calculated.

Table2. Distribution of coefficients X1 and X2

X	ƛ	X1	ΣX=0 X2	ΣX=0.5 X2	ΣX=1 X2
-0.5	0.5	0	0	0.5	1
	0.6	0.0333	-0.0333	0.4666	0.966
	0.75	0.0833	-0.0833	0.4166	0.916
0	0.5	0.1666	-0.1666	0.3333	0.833
	0.6	0.2	-0.2	0.3	0.8
	0.75	0.25	-0.25	0.25	0.75
0.6	0.5	0.3666	-0.36666	0.1333	0.633
	0.6	0.4	-0.4	0.1	0.6
	0.75	0.45	-0.45	0.05	0.55

To generate above table , X and ƛ values are selected from the limit specified in IS standard. And then X1 and X2 coefficients have been distributed so that we can get S-gearing, So-gearing and Sn-gearing.By considering these three types of gearing for same gear pair , we can see the root stress variation with respect to addendum coefficients X1 and X2 .

From this table we get 27 different combination of gears for same selected gear pair mentioned above. With these combinations root stresses have been calculated by Lewis bending equation to study the variation of stresses with addendum modification coeffients.

Results of these calculation are tabulated as below:

Table3.Root stresses Analytical Values

	x1	x2	Root stress (MPa)
ΣX=0	0	0	8.442951018
	0.033	-0.033	8.443831856
	0.083	-0.083	8.445092364
	0.166	-0.166	8.446986964
	0.2	-0.2	8.44769152
	0.25	-0.25	8.448651848
	0.366	-0.366	8.45053119
	0.4	-0.4	8.450989421
	0.45	-0.45	8.451586828
ΣX=0.5	0	0.5	8.436272659
	0.033	0.466	8.437315925
	0.083	0.416	8.438799795
	0.166	0.333	8.441067511
	0.2	0.3	8.441911858
	0.25	0.25	8.443099359
	0.366	0.133	8.445521422
	0.4	0.1	8.446123573
	0.45	0.05	8.446951383
ΣX=1	0	1	8.42734323
	0.033	0.966	8.428533812
	0.083	0.916	8.430235285
	0.166	0.833	8.432867139
	0.2	0.8	8.433857154
	0.25	0.75	8.435266499
	0.366	0.633	8.438212168
	0.4	0.6	8.438963006
	0.45	0.55	8.440016991

FEM Analysis:

The stress values calculated by Lewis Bending equation are verified by performing FEM analysis. For this CAD models of some of the gear pairs have been created using CREO 2.0 software. These model were imported into ANSYS software and stress analysis was carried out.

Table4.Gear pair selection for Cad and FEM

SN	X1	X2	ΣX=X1+X2
1	0.2	-0.2	ΣX=0
	0.45	-0.45	
2	0.2	0.3	ΣX=0.5
	0.4	0.1	
3	0.2	0.8	ΣX=1
	0.45	0.55	

In Table.3, there are total 27 no of gear pair with different addendum modification coefficients X1 and X2. For FEM analysis arbitrarily two gear pairs have been selected from each of ΣX=0 , ΣX=0.5, ΣX=1. And with Table.4 is prepared for further analysis.

The following image shows a CAD model of gear pair with X1=0.2 and X2= -0.2.

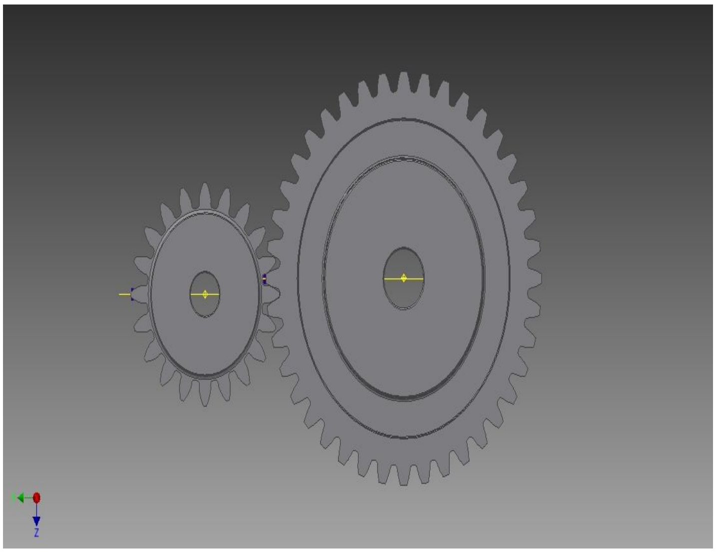

Fig.1.Cad model of gear pair

FEM Model:

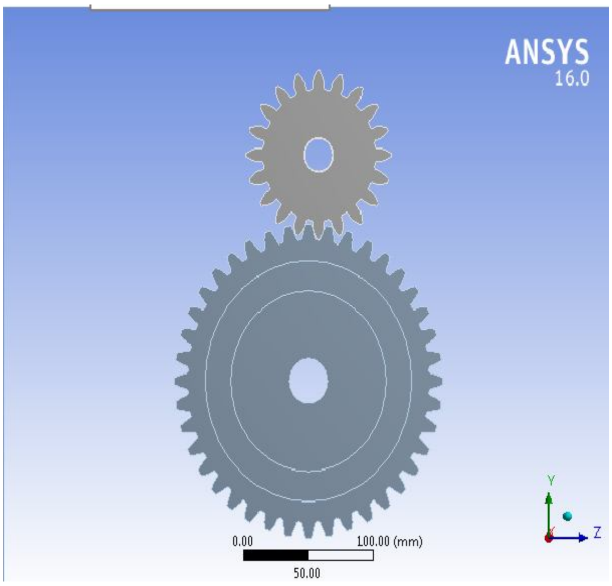

Fig.2.Workbench Model of gear pair

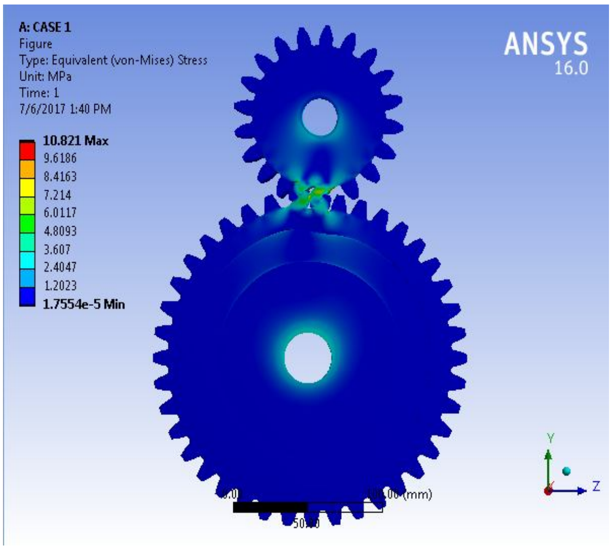

Fig.3.stress analysis result of gear pair

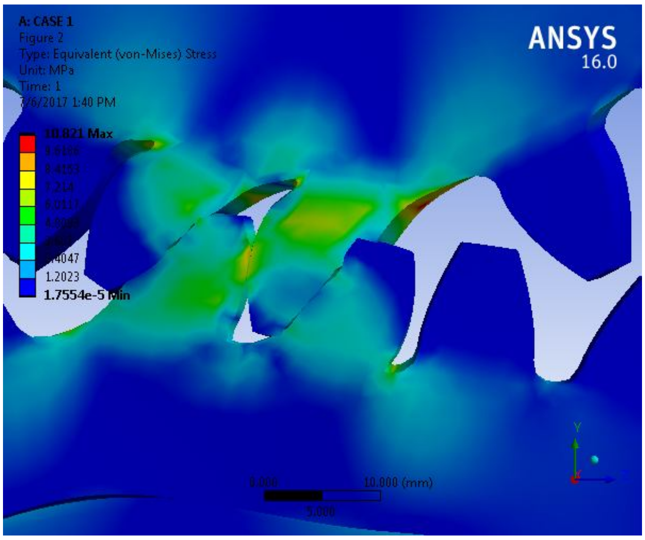

Fig.4.Zoomed view of tooth at meshing points

Similar stress analysis was carried out on remaining 5 gear pair from table.4. The results obtained of root stresses by FEM are close to Analytical results obtained by equation (1).

SN	X1	X2	RootStress(MPa)
1	0.2	-0.2	10.82
	0.45	-0.45	11.43
2	0.2	0.3	9.68
	0.4	0.1	10.87
3	0.2	0.8	10.43
	0.45	0.55	9.58

The stresses obtained by ANSYS are not exact but these stresses are within 20% variation.This 20% error can be due to mesh setting , geometry construction in CAD software.

Graphs:

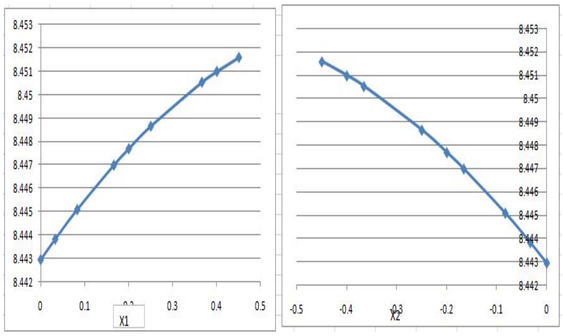

Fig.5.Graph of Root stress vs X1 and X2 for ΣX=0

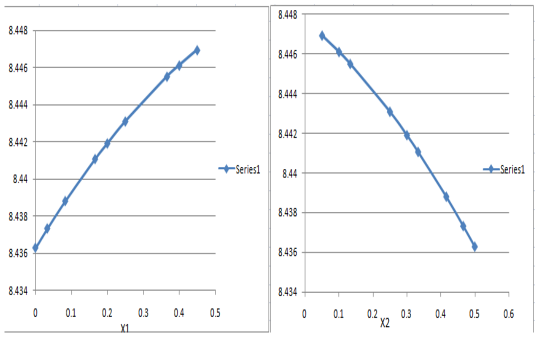

Fig.6.Graph of Root stress vs X1 and X2 for ΣX=0.5

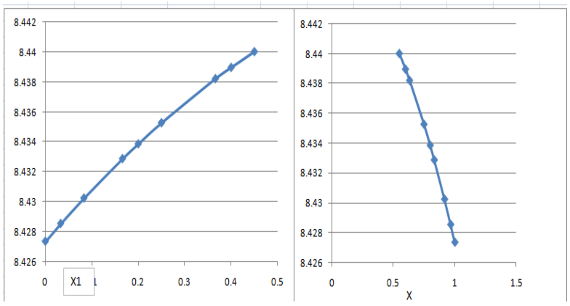

Fig.7.Graph of Root stress vs X1 and X2 for ΣX=1

II. CONCLUSION

1. When addendum modification coefficients are distributed between pinion and gear by taking ΣX=0(So- Gearing), we found that stresses are increasing continuously with increasing X1 and X2(-Ve values). This can be seen from fig.5
2. In fig.6 and fig.7, X1 and X2 are distributed such that ΣX=+Ve Number.(0.5 and 1.0 for selected gear pair). Here as X1 increases root stresses are increasing but reverse effect is observed with X2.So pinion may be used without modification while gear can be provided with a Addendum modification to have minimum stress value.
3. As we change the gear ratio, addendum modification coefficients values will also change, as these values depends on gear profile restriction.

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TABLE I
UNITS FOR MAGNETIC PROPERTIES (SHORT TITLE HERE)

Symbol	Quantity	Conversion from Gaussian and CGS EMU to SI [a]
Φ	magnetic flux	1 Mx → 10^{-8} Wb = 10^{-8} V·s
B	magnetic flux density, magnetic induction	1 G → 10^{-4} T = 10^{-4} Wb/m^2
H	magnetic field strength	1 Oe → $10^3/(4\pi)$ A/m
m	magnetic moment	1 erg/G = 1 emu → 10^{-3} A·m^2 = 10^{-3} J/T
M	magnetization	1 erg/(G·cm^3) = 1 emu/cm^3 → 10^3 A/m
$4\pi M$	magnetization	1 G → $10^3/(4\pi)$ A/m
σ	specific magnetization	1 erg/(G·g) = 1 emu/g → 1 A·m^2/kg
j	magnetic dipole moment	1 erg/G = 1 emu → $4\pi\times 10^{-10}$ Wb·m
J	magnetic polarization	1 erg/(G·cm^3) = 1 emu/cm^3 → $4\pi\times 10^{-4}$ T
χ, κ	susceptibility	1 → 4π
χ_ρ	mass susceptibility	1 cm^3/g → $4\pi\times 10^{-3}$ m^3/kg
μ	permeability	1 → $4\pi\times 10^{-7}$ H/m = $4\pi\times 10^{-7}$ Wb/(A·m)
μ_r	relative permeability	$\mu \rightarrow \mu_r$
w, W	energy density	1 erg/cm^3 → 10^{-1} J/m^3
N, D	demagnetizing factor	1 → $1/(4\pi)$

No vertical lines in table. Statements that serve as captions for the entire table do not need footnote letters. A longer description of the table would go here.

[a]Gaussian units are the same as cgs emu for magnetostatics; Mx = maxwell, G = gauss, Oe = oersted; Wb = weber, V = volt, s = second, T = tesla, m = meter, A = ampere, J = joule, kg = kilogram, H = henry.

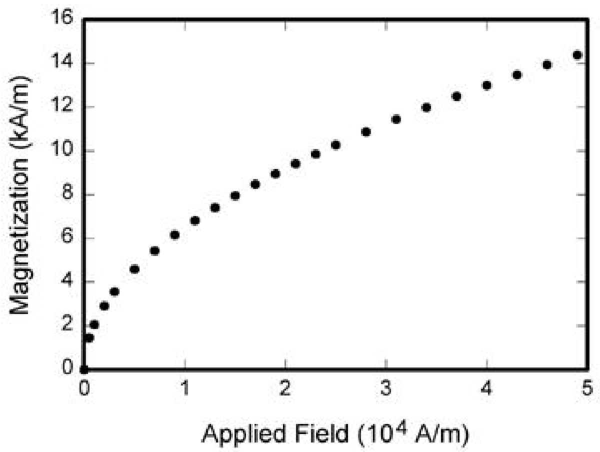

Fig. 1. Magnetization as a function of applied field. Note that "Fig." is abbreviated. There is a period after the figure number, followed by two spaces. It is good practice to explain the significance of the figure in the caption.