Stress Analysis of Spur Gear with Circular & Normal Fillet Using ANSYS

[1]K. Surendra Babu, [2]Md. Abid Ali, [3]C. Srilatha
[1] Asst. Professor, PSCMRCET, [2] Asst. Professor, PSCMRCET, [3] Professor, PSCMRCET
[1] sbkoganti51@gmail.com [2] drmaa@gmail.com [3]srimanitha.2002@gmail.com

Abstract:

Gears are widely used components in mechanical power transmission systems. This article investigates the shear stresses and bending stresses developed in spur gear tooth of planetary gearbox which is used in Snag Crane. In this study, the calculation for bending stress & shear stress for spur gear tooth using theoretical method is done. The model was created using modeling software and the analysis is done using ANSYS. Using ANSYS the analysis is performed on the root fillet of the spur gear tooth. The analysis is done in two conditions as circular root fillet and normal root fillet of a gear tooth. The results of the analysis from ANSYS are compared with the theoretical values. Comparison of theoretical shear stress and bending stress values with ANSYS results in circular root fillet & normal root fillet is also done.

Keywords: Bending Stress, Circular Root Fillet, Snag Crane, Planetary Gearbox, Shear Stress

I. INTRODUCTION

Even though there is a lot of research in finding the stresses in gears, there remains something to be developed. The aim of this work is to use 3D model created using a modelling software and analyze the stresses using ANSYS to develop theoretical models of the behavior to predict the effect of gear tooth stresses. The main focus of the current research as developed here is to to find bending and shear stresses using ANSYS and compare the results with theoretical.

This work mainly deals with

1) Checking of bending stresses using IS 4460 equations for spur gear.
2) Force calculations for spur gear used in planetary gear box in a snag crane.
3) Calculate the values for spur gear tooth for bending and shear using theoretical method.
4) Create 3D model of circular root fillet & trochoidal root fillet of gear tooth for simulation using Pro-E.
5) Importing 3Dmodel in ANSYS.
6) Comparison of bending & shear stress of the 3D analyses from ANSYS with the theoretical values.
7) Comparison of ANSYS results in circular root fillet & normal root fillet.

II. LITERATURE SURVEY

Shanmugasundaram Sankar, Maasanamuthu Sundar Raj & Muthusamy Nataraj [1] have introduced Correc- tive measures are taken to avoid tooth damage by intro- ducing profile modification in root fillet. Tesfahunegn and Rosa [2] investigated the influence of the shape of profile modifications on transmission error, root stress and con- tact pressure through non linear finite element approach. Chun-Fang Tsai ,Tsang-Lang Liang & Shyue-Cheng Yang [3] prepared a complete mathematical model of the pla- netary gear mechanism with double circular-arc teeth is developed. Ravichandra Patchigolla and Yesh P. Singh [4] developed a program using ANSYS Parametric De- sign Language (APDL) to generate 1, 3 or 5 tooth segment finite element models of a large spur gear. Faydor L. Lit- vin, Alfonso Fuentes, Daniele Vecchiato, and Ignacio Gonzalez-Perez [5] proposed a new types of planetary and planetary face-gear drives & the new designs are based on regulating backlash between the gears and mo- difying the tooth surfaces to improve the design.

III. TERMINOLOGY

2.1. Terminology—Spur Gears

- Diametric pitch (dp): The number of teeth per one inch of pitch circle diameter.
- Module (m): The length, in mm, of the pitch circle diameter per tooth.
- Circular pitch (p): The distance between adjacent teeth measured along the pitch circle diameter
- Addendum (ha): The height of the tooth above the pitch circle diameter.
- Centre distance (a): The distance between the axis of two gears in mesh.
- Circular tooth thickness (Ctt): The width of a tooth measured along the are at the pitch circle diameter.
- Dedendum (hf): The depth of the tooth below the pitch circle diameter.
- Outside diameter (Do): The outside diameter of the gear.
- Base Circle diameter (Db): The diameter on which the involute teeth profile is based.
- Pitch circle dia (D): The diameter of the pitch circle.
- Pitch point: The point at which the pitch circle diameters of two gears in mesh coincide.

- Pitch to back: The distance on a rack between the pitch circle diameter line & the rear face of the rack.
- Pressure angle: The angle between the tooth profile at the pitch circle diameter & a radial line passing through the same point.
- Whole depth: The total depth of the space between adjacent teeth.

IV. SNAG CRANE SPECIFICATION

Capacity: 10 Ton wire rope (weight of material handled + grab)

Duty: Class 4/12 Hr
Location: Outdoor

Total weight of trolley: 13 T Total weight of crane: 71 T Ambient temperature: 50˚C Lubrication: Group Operations from: Closed cabin

Grab bucket capacity: 3.5 m^3

Material handled: Blast furnace slag
Bulk density: 1.1 - 1.2 T/m^3

Weight of material handled: 4 T Dead weight of grab bucket: 5.5 T

Normal Rating:
The normal ratings of the gears is the allowable continuous load for 12 hours running time per day.

Duty Factor:

1. For Class III Crane: Duty factor for wear = 0.6
   Duty factor for strength = 1.4
2. For Class IV Crane: Duty factor for wear = 0.7
   Duty factor for strength = 1.6

V. THEORETICAL CALCULATIONS

Normal reaction

= Capacity

= Volume of bucket × density of material

= 3.5 × 1.1 × 1000

= 3850 Kg

= 3.85 T

Assuming coefficient of frictions, μ = 0.1 Friction force = μN = 0.1 × 3.85= 0.385 T

Torque = Force × Perpendicular distance

= 0.385 x 1.8

Time required to grab 1 Ton of slag

= Displacement/ Velocity

= 1.8/20 =0.09 min

Speed = 0.5/0.09 = 5.56 rpm

From standard formulae,

$$T = \frac{736 \times HP}{rpm}$$

$$693 = \frac{736 \times HP}{rpm}$$

HP = $HP_{induced}$ = 5.23

Bending Stress:

σ_b = Bending Stress

The classic method of estimating the bending stresses in a gear tooth is the Lewis equation. It models a gear tooth taking the full load at its tip as a simple cantilever beam.

Lewis Bending Stress From,

$$\sigma_b = \frac{W_t P_d}{FY} = \frac{W_t \pi}{mFY}$$

W_t is the tangential load

P_d is the diametral pitch

F is the face width

Y is the Lewis form factor

m is the module

Since tangential load

$F_t = W_t$ =112858.33 act on 3 no. teeth, hence tangential load

F_t = W_t act on single teeth = 112858.33 /3 = 37619.443 N

W_t = 37619.443 N

F is the face width = 120 mm

Y is the Lewis form factor for 18 No. Teeth = 0.308

m is module = 6 mm

$$\sigma_b = \frac{37619.443 \times \pi}{6 \times 120 \times 0.308}$$

$\sigma = 532.94\ N\ mm^2$

Shear Stress:

$$\sigma_s = \frac{Load}{Area} = \frac{F_t}{b \times Tooth\,Width}$$

$$= \frac{F_t}{b \times (\pi \times m)/2}$$

$$= \frac{37619.443}{120 \times (\pi \times 6)/2}$$

$\sigma_s = 33.2495077\ N/mm^2$

VI. GEOMETRIC MODELING

Consider the involute spur Gear, gear tooth of circular fillet illustrated in **Figure 1** where point O is the center of the gear, axis Oy is the axis of symmetry of the tooth & point B is the point where the involute profile starts (form the form circle rs). A is the point of tangency of the circular fillet with the root circle rf. Point D lying on (e2) OA represents the center of the circular fillet. Line (e3) is tangent to the root circle at A & intersects with line (e1) at C. The fillet is tangent to the line (e1) at point E. Since it is always rs > rf , the proposed circular fillet can be implemented without exceptions on all spur gears irrelevant of number of teeth or other manufacturing parameters. A comparison of the geometrical shape of a tooth of circular fillet with that of normal fillet is presented in **Figures 2**.

A finite element model with a single tooth is considered for analysis. Gear material strength is a major consideration for the operational loading & environment. In modern practice, the heat treated alloy steels are used to overcome the wear resistance. ANSYS version 10.0 software is used for analysis. In this work, heat treated alloy is taken for analysis. The gear tooth is meshed in 3-dimensional (3-D) solid 16 nodes 92 elements with fine mesh. SOLID92 has a quadratic displacement behavior & is well suited to model irregular meshes.

For spur gear used in snag crane's hoist **Figure 3** and **4** indicates the PRO-E (3-D View) of actual and Circular Fillet Tooth respectively. Also **Figures 5** and **6** indicates the Meshing of Actual & Circular Fillet Tooth respectively in ANSYS.

The following are the material properties used

Gear material: [3% nickel steel with BHN 620 (case)]

Density: 7800 kg/m^3

Young's modulus: 2×10^5 N /mm^2

Poisons ratio: 0.3

Yield strength: 28.12 kg/mm^2

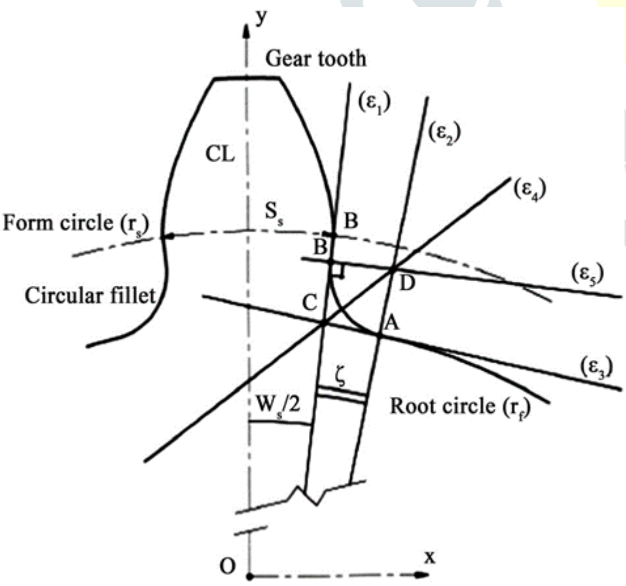

Figure 1. Geometry of the Circular Fillet.

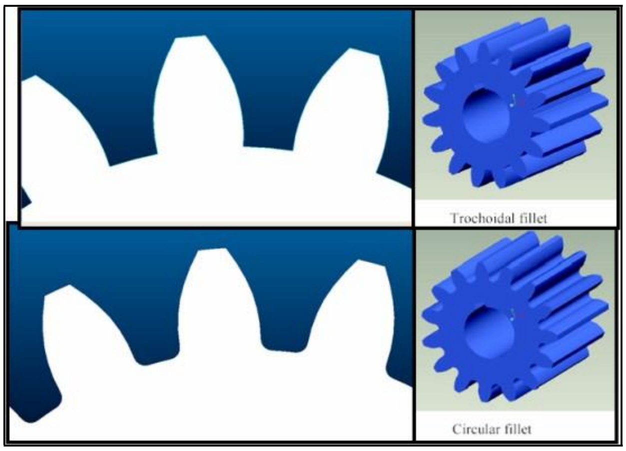

Figure 2. Geometrical Modeling: Normal & circular fillet spur gear

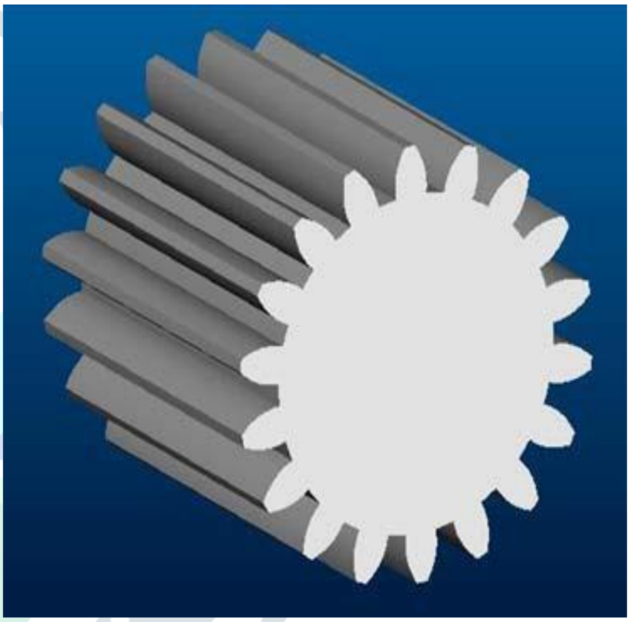

Figure 3. Normal fillet tooth sun gear in PRO-E (3D view).

Figure 4. Circular fillet tooth sun gear in PRO-E (3D view).

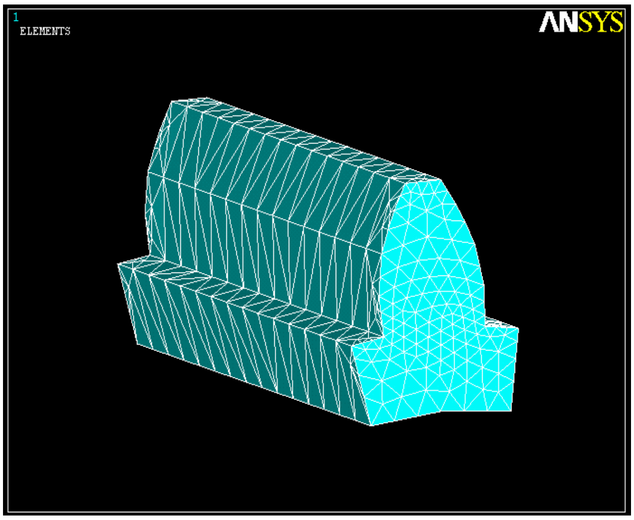

Figure 5. Meshing of normal tooth fillet spur gear in ANSYS

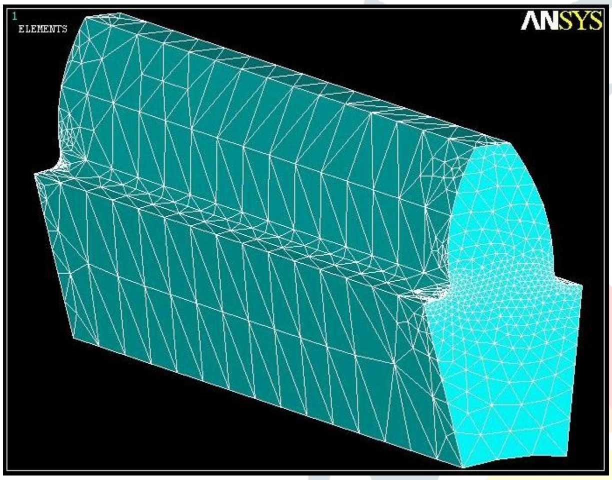

Figure 6. Meshing of circular fillet tooth sun gear in ANSYS

VII. RESULTS

Refer **Figures 7-10** for ANSYS. Analysis for bending, shear, wear stress & deflection of sun gear used in grab crane's hoist. All results summarized in **Table 1.**

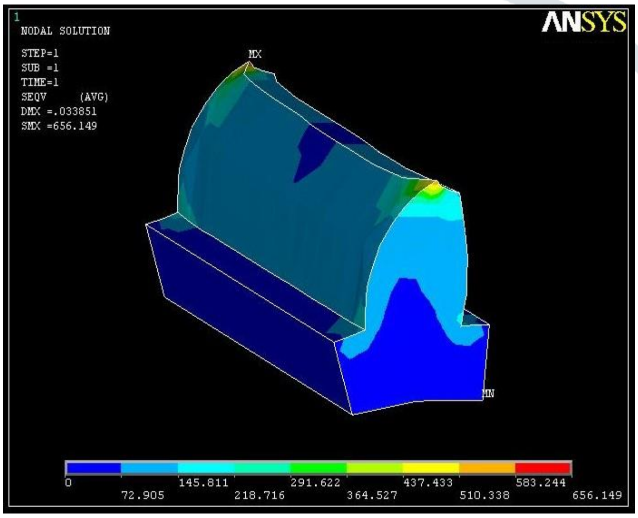

Figure 7. Bending stress - Normal fillet result: Maximum induced σ_b = 656.149 N/mm^2

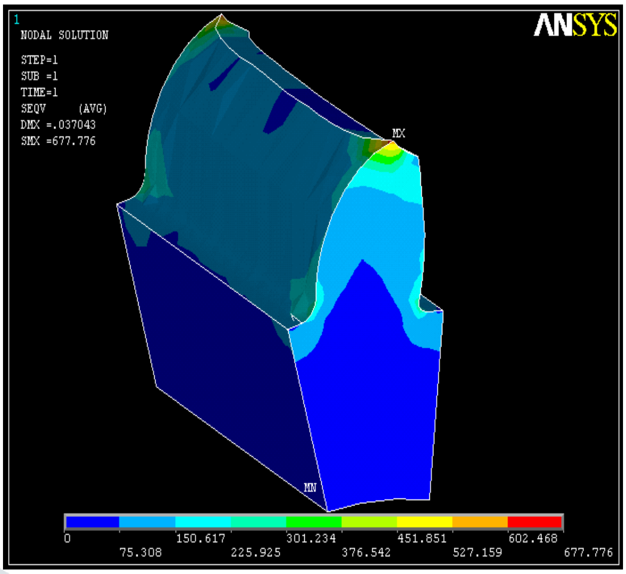

Figure 8. Bending stress - Circular fillet result: Maximum induced σ_b = 677.776 N/mm^2

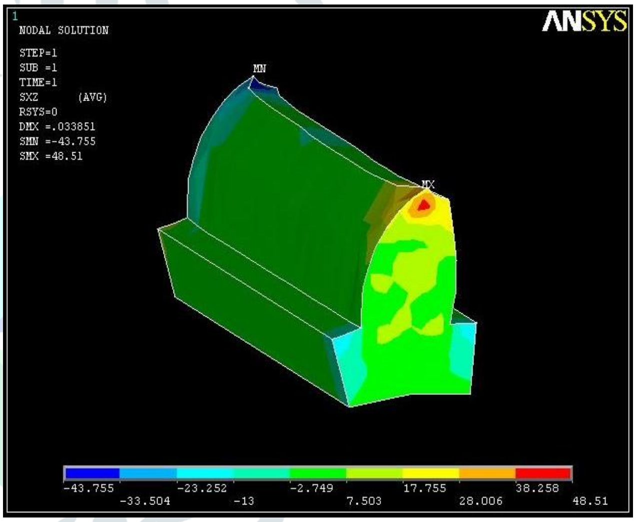

Figure 9. Shear stress-Normal fillet result: Maximum induced σ_s = 48.51 N/mm^2

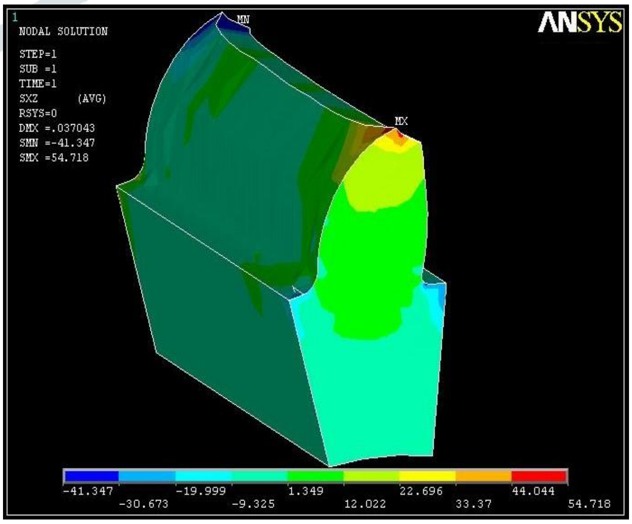

Figure 10. Shear stress - Circular fillet result: Maximum induced σ_s = 54.71 N/mm^2.

Table 1. Bending & Shear Stresses Result

Analysis	Theoretical Value	By ANSYS	
		For Actual Fillet	For Circular Fillet
Bending Stress (N/mm^2)	532.94	656.149	677.776
Shear Stress (N/mm^2)	33.24	48.51	54.71

VIII. CONCLUSIONS

ANSYS results for various stresses are nearer to theoretical values for spur gear used in planetary gear system in snag crane. There is appreciable reduction in bending & shear stress value for actual root fillet design in comparison to that of stress values in circular root fillet design. However, from the foregoing analysis it is also found that the circular fillet design is more optimum for lesser number of teeth in pinion & actual fillet design is more suitable for higher number of teeth in gear (more than 17 teeth) & whatever may be the pinion speed. In addition to that the ANSYS results indicates that the gears with actual root fillet design will result in better strength, reduced bending stress & also improve the fatigue life of gear material.

IX. REFERENCES

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