Optimization of design based on Fillet radius and tooth width to minimize the stresses on the Spur Gear with FE Analysis

Y. Sandeep kumar, R.K. Suresh, B.Jayachandraiah

Abstract: Gears are one of the most critical components in mechanical power transmission system. Spur gears are mostly used in the applications varying from domestic items to heavy engineering applications. The contact stress and tooth stresses due to transmission depends on some parameters.

In this paper the effect of tip radius, tooth width is considered and how the contact stress results vary with these parameters is studied. The Gear design is optimized based on FE analysis. The stresses were calculated using the Lewis equation and then compared with the FE model. The Bending stresses in the tooth root and at mating region were examined using 3D FE mode.

Keywords: GEAR FE MODEL, FILLET RADIUS, 3D FEM

I. INTRODUCTION:

Spur gears are the simplest type of gear. They consist of a cylinder or disk with the teeth projecting radially, the edge of each tooth is straight and aligned parallel to the axis of rotation. These gears can be meshed together correctly only if they are fitted to parallel shafts. The main reason for the popularity of spur gears is their simplicity in design and manufacturing.

In Spur gears the design parameters play a major role in determination of stresses. The AGMA Standards set by American Gear Manufacturing Association are usually followed in design of Spur gear.

In this paper the two parameters i.e tip radius and tooth width which play a key role in gear design are studied. These parameters are varied and their effects on the final stress are observed at the root and mating regions of the gear.

A gear was considered which was mating with similar kind of the gear and then FE Model was built in CATIA V5. Using Lewis Equation and AGMA Standards the stresses were calculated and the FE model was solved using RADIOSS solver and results were compared.

The results were optimized for best results with the variation of two parameters tip radius and tooth width so that the stresses are minimized.

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II. LITERATURE REVIEW:

A recent study by Kahraman considers each gear as a deformable body and meshes them to predict load, stress and deformations. Based on these results presented, a deformable body analysis with a thin rim is necessary. [1]

Deng used tooth contract analysis, loaded tooth contact analysis and finite element method to analyze the meshing behavior, tooth surface contract stress, maximum tensile, bending stress and maximum compressive bending stress. The modified pitch cone method is first presented and verified in the gear research center of Dong Feng vehicle-bridge Co., Ltd. [2]

3D static and dynamic contract/impact analysis of gear drives were developed by Rufang Li. The tooth load allocation and result are derived under the static load. This paper analyzes the stress distribution of gear system under dynamic loading conditions and simulates the stress of gears under conditions of initial speed and a sudden load being applied. [3]

Mao developed an advanced non-linear finite element method, which has been successfully used to accurately simulate gear contact behavior under real load conditions. [4]

For a gears the stresses were firstly computed by the 2D FEM [5,6] and the formuale were drawn allowing a simple calculation of maximum tooth root strsses.

3. MODELING OF THE SPUR GEAR

According to the described procedure the gear pair with the following parameters was modeled using CATIA V5R12.

Modeling of gear using the CATIA consists of two steps, one is part design and another Assembly design. Part and Shape design are the basic modules of design in CATIA software. They are based on several tools for easy and qualitative modeling of any kind of machine elements. First step of design any part is to define position (plane) of Sketch and to draw profile in chosen Sketch.

Some operations consist in adding material, others in removing material for example Create a Pad, Pocket, Shaft, Groove, Hole, Slot, and Loft etc.

Assembly design is another module in CATIA which is in use in aim to complete all parts and standard elements that are already modeled in Part or Shape design. Besides it is possible to insert new bodies in existing assembly and also to do Boolean Operations between bodies if it is necessary. These Boolean operations between bodies are Assemble Bodies, Intersect Bodies, Add Bodies, Remove Bodies, Trim Bodies, and Remove Lumps etc.

Table 3.1 Gear specifications

Number of teeth	20
Module(m)	4
Pitch Circle diameter	80
Base circle diameter	70
Pressure angle	20
Addendum circle diameter	88
Circular pitch	12.56
Thickness of tooth	6.25

Material assigned to both gears was steel with following material properties

Modulus of elasticity E= 210000 Mpa
Poisson's ration v= 0.3

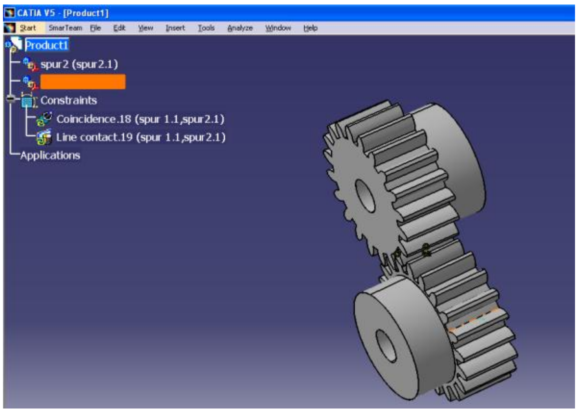

Fig3.1: Modeling of spur gear assembly using CATIA V5

4. FINITE ELEMENT MODEL OF THE SPUR GEAR:

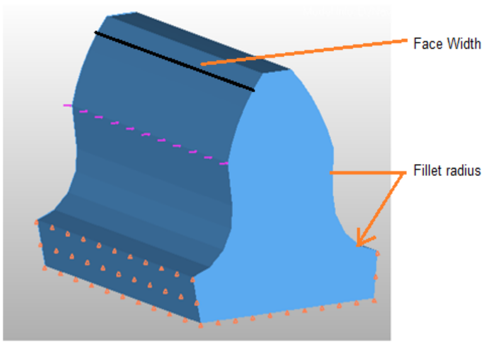

Fig 4.1 FE Representation of the Model

A finite element model with a segment of one tooth is considered for analysis. The gear tooth was meshed with 3D elements like Hexa and penta elements. A point load of 2500N was applied at tip of the gear. Figure 4.1 shows the finite element model with boundary conditions.

The basic procedure steps as follows

- The three dimensional model of the gear was created using the CATIA software.
- The model was meshed using Finite element software as HYPERMESH.
- Boundary conditions were given on the finite element model through RADIOSS.

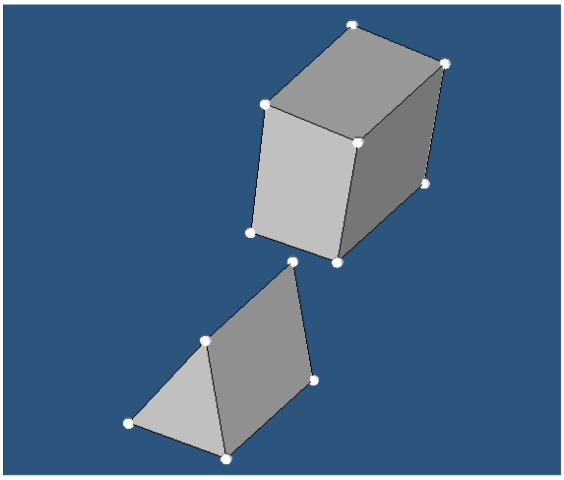

Fig 4.2 hexa and penta eliments

V. DATA COLLECTION:

There are several failures mechanisms for spur gears. Bending failures is one of the main failure modes in a transmission gear box. The Bending stresses in a spur gear is predicted by comparing the calculated bending stresses to experimentally determined allowable limit for the given material.

5.1 LEWIS EQUATION:

This bending stress equation was derived from the LEWIS Equation.

$$\sigma_W = \frac{M \times Y}{I}$$

$$= \frac{(W_T \times h)^{t}/2}{bt^3/12} \quad \ldots\ldots\ldots\ldots(5.1.1)$$

W_T = Tangential load acting at the tooth

$$= \frac{\sigma_W \times b \times t^2}{6h}$$

M is the maximum bending moment at the critical section BC, h is Length of the teeth, y is half the thickness of the tooth (t) at critical section BC, and I is Moment of inertia about the centre line of the tooth, and b is width of gear face.

5.2 AGMA STANDARDS:

The contact stress by AGMA standards are introducing the factors K_v, K_0 and K_m used in the bending fatigue analysis into the contact stress equation, the dynamic contact stress is obtained as σ_H

$$\sigma_H = C_p \sqrt{\frac{F_t}{bd_l I} K_V K_o K_m}$$

$$C_p = 0.564 \sqrt{\frac{1}{\frac{1-\mu_1^2}{E_1} + \frac{1-\mu_2^2}{E_2}}}$$

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Where

K_v = Velocity or Dynamic factor
= (6+V)/6

K_0 = Overload factor which reflects the degree of non-uniformity of driving and load torques.

Km = load distribution factor which accounts for non uniform spread of load across the face width.

VI. RESULTS & DISCUSSIONS:

Stress Contour

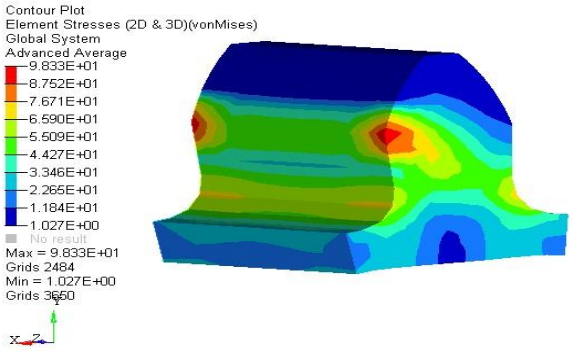
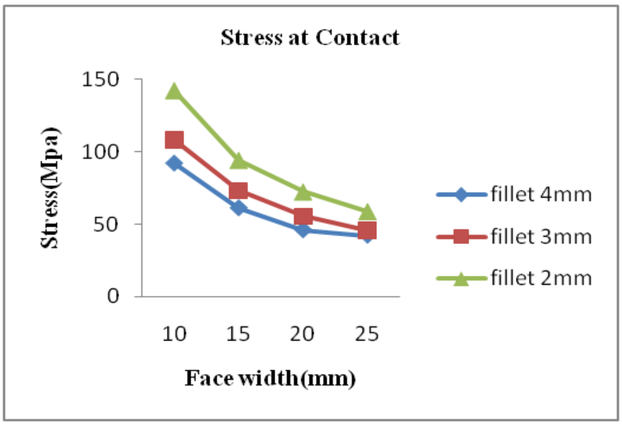
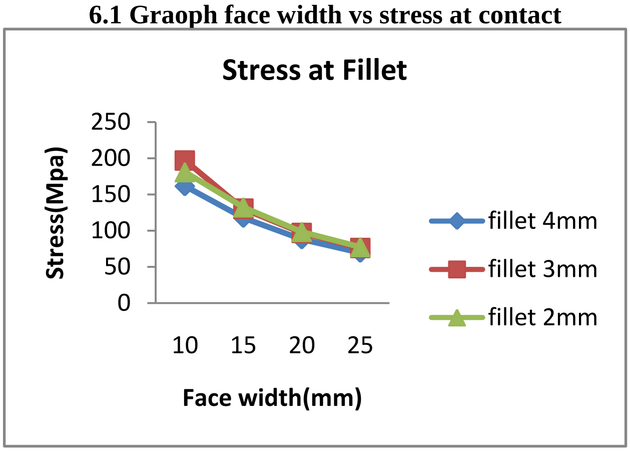


Fig 6.1 FE Result



6.1 Graoph face width vs stress at contact



6.2 Graph face width vs stress at fillet

VII. VALIDATION OF THE RESULTS FOR FILLET RADIUS 3 MM:

The FEA results of bending stress are compared with the stress calculated Table 6.1 using the gear related procedure specified in AGMA standards. The FEA results are found to be in close agreement with the calculated stresses based on AGMA Standards for the specific geometry configuration of the gear.

From the Equation (5.1.1)

$\sigma_w = (2500\times5\times6)/20\times(6.25)^2$
$= 96$ Mpa

Table 7.1 Comparison of results

Face width	Lewis equation	AGMA	FEA	%of error (Lewis equation and FEA)	% of error (AGMA And FEA)
10	192	186	197	2.6	5.91
15	128	124	130	1.56	4.83
20	96	93	97	1.04	4.30
25	77	75	76	1.31	1.33

VIII CONCLUSION:

The comparison of two errors is closely matched in 25mm width of gear. So the optimum result to minimize the stress value whiles the fillet radius of 3mm and face width of 25mm. The Stress at the contact and fillet region decreases with the increase of face width.

The FEA results are found to be in close agreement with the calculated stresses based on AGMA standards and Lewis Equation.

FUTURE WORK:

In this research work the air is considered in contact zone of two meshing teeth. If the oil film is considered the CFD Analysis is coming to the picture.

A whole gear box with all elements in the system such as the bearing and the gear casing is considered instead of one tooth.

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