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Static and Dynamic Analysis of Involute Spur Gears with Circular Tooth Fillet

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ABSTRACT

Generally, the gear tooth failure is due to high load carrying capacity, rotation speed etc. The goal of this project is to study the effects of tooth stresses and tooth deflection in spur gear drive at critical zones of single tooth contact. Heavy bending is occurred in the fillet of the gear tooth. Corrective measures are taken to avoid tooth damage by introducing circular root fillet instead of the standard trochoidal root fillet. The modified fillet gives reduction of bending and contact stresses. The performing constraints of standard and circular fillet spur gears were determined through Finite Element Analysis (FEA). Contact parameters viz. contact stress, normal displacement and tooth mesh stiffness were theoretically determined at the contact area. The circular root fillet withstands higher bending strength rather than the standard root fillet design. The spur gear is modeled in "CATIA" and imported to "FEMAP NX NASTRAN" for static and dynamic analysis. The results from the analysis were validated with theoretical calculations by Lewis equation and Hertezian equation.

Keywords: ***Circular root fillet, Standard root fillet, Spur gear, Bending stress, Contact Stress, Static Analysis***

INTRODUCTION

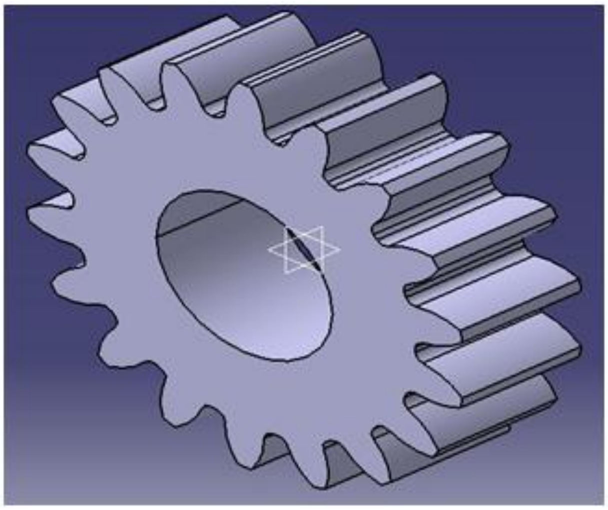
Gear is one of the most common components which are widely used mechanical power transmission system. A gear wheel has cut teeth which mesh with another cutted toothed part to transmit torque. Gears always produce a change in torque which gives a mechanical advantage of controlling the motion or torque, the change of the torque is controlled by their gear ratio. The tooth of the two mating gears should have same shapes ,if two or more meshing gears are working in a sequence then they are called gear train .a gear can also mesh a linear toothed part called rack.

The gears are very effective in transmitting power from one shaft to another because of its high degree of reliability and compactness. Gear tooth stresses and deflection are determined for standard spur gears adopting FEA. Appropriate contact elements are selected for tooth contact analysis.

SPUR GEAR

The spur gear is simplest type of gear manufactured and is generally used for transmission of rotary motion between parallel shafts. The spur gear is the first choice option for gears except when high speeds, loads, and ratios direct towards other options. Other gear types may also be preferred to provide more silent low-vibration operation. A single spur gear is generally selected to have a ratio range of between 1:1 and 1:6 with a pitch line velocity up to 25 m/s. The spur gear has an operating efficiency of 98-99%. The pinion is made from a harder material than the wheel. The minimum number of teeth on a gear with a normal pressure angle of 20 degrees is 18.This is a cylindrical shaped gear in which the teeth are parallel to the axis. It has the largest applications and, also, it is the easiest to manufacture.

They are simple in construction, easy to manufacture and cost less.



They have highest efficiency and excellent precision rating. They are used in high speed and high load application in all types of trains and a wide range of velocity ratios. Hence, they find wide applications right from clocks, household gadgets, motor cycles, automobiles, and rail ways to aircrafts.

LITERATURE SURVEY

Sankar and Nataraj [1] has that reduction in bending stress and contact shear stress for circular root fillet design in comparison to standard root fillet design. And also indicate the gears made of circular root fillet yield better strength, there by improve the fatigue life of the gear material. S. Senthilvelan, R. Gnanamoorthy [2] In metal gears the gear manufacturing process and cutting tool dimensions decide the gear tooth geometry and affect the gear performance. In this paper, the effect of gear tooth fillet radius on the performance of injection molded Nylon 6/6 gear made with different tooth fillet radius 0.25 and 0.75 mm is reported. Finite element analysis carried out indicates high fillet root stresses and gear tooth deflection in gears with low fillet radius Gurumani, R. and S. Shanmugam [3] Modeling and contact analysis of crowned external involute spur gears. This paper provides a novel method to model lead crowned spur gears. The teeth of circular and involute crowned external spur gears are modeled for the same crowning magnitude. Based on the theory of gearing, mathematical model of tooth generation and meshing are presented. Effect of major performance characteristics of uncrowned spur gear teeth are studied at the pitch point and compared with longitudinally modified spur gear teeth. B. Venkatesh[4] obtained Von-Misses stress by theoretical and ANSYS software for Aluminum alloy, values obtained from ANSYS are less than that of the theoretical calculations. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions, which are safe and less than the other materials like steel. Aluminum alloy reduces the weight up to 5567% compared to the other materials. Aluminum is having unique property (i.e. corrosive resistance), good surface finishing, hence it permits excellent silent operation. Weight reduction is a very important criterion, in order to minimize the unbalanced forces setup in the marine gear system, there by improves the system performance. Spital and costopoulos [5] have carried out an analysis by introducing circular root fillet instead of the standard root fillet in the spur gear. The analysis infers that the teeth with circular fillet design exhibits higher bending strength in certain cases without affecting the pitting resistance, since, the geometry of the load carrying involute is not changed. Hebbal and Math [6] have reduced the root fillet stress in spur gear using internal stress relieving feature of different shapes. The maximum principal stress at the root on the tensile side of tooth was used for evaluating the tooth bending strength of a gear. Contact stress at the contact region of the pinion was found. By considering the fact that the load is usually shared between two tooth pairs when the contact is away from the pitch point, the compressive stress at the pitch line is used as the critical contact stress. Beghini, F. Presicce and C. Santus [7] proposed a simple method to reduce the transmission error for a given spur gear at the nominal torque by means of the profile modification parameters. Researchers focused either on the development of advanced materials or new heat treatment methods or designing the gears with stronger tooth profiles. Gears having standard involute with smaller number of teeth (i.e., less than 17 teeth) had the problem of undercutting. In gear manufacturing process the tooth root fillet is generated as the tip of the cutter confiscates material from the involute profile

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FINITE ELEMENT ANALYSIS OF TOOTH CONTACT

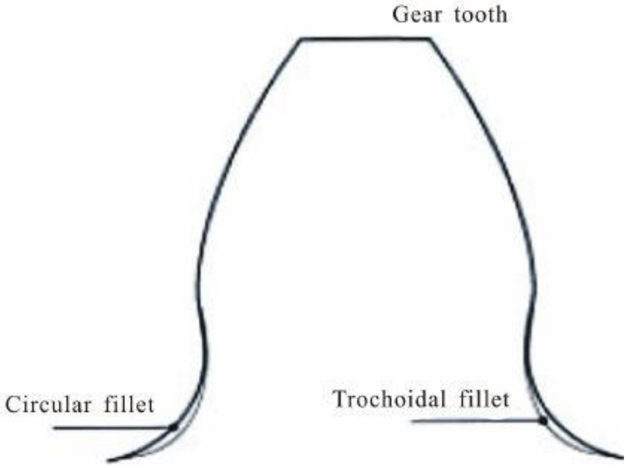
The most prevailing method of defining accurate stress and deflection evidence is the finite element method.

Gear tooth geometry is a replica of the simple cantilever beam model according to Lewis beam strength equation where one tooth is considered as a base and the root is fixed. The loads interim on the mating gears will deed along the pressure line, which can be committed into both tangential and radial components using the pressure angle. The radial constituent of force is deserted and the effect of only tangential component is deliberated as uniformly distributed load at the line of contact. In the case of crowned gears, entire load is assumed to take place at the point of contact. A thick full rim with three tooth finite element model was used for stress analysis.

The dynamic response of the arrangement was deserted; henceforth the results are related to static loaded tooth contact analysis. Loading was applied as input torque at the gear centres. It is not suggested to have a fine mesh everywhere in the model, in order to reduce the computational requirements. In the gear development of advanced materials, new heat treatment methods, designing the gear with stronger teeth, and methods of gear manufacturing to take the problem of failure of gears. In the present work, involute spur gear teeth for fillet radius designated taken for analysis. Involute spur gear teeth are also measured for bending stress and tooth contact analysis.

Their performance behavior is calculated by assuming loading at pitch point underneath static load, frictionless support and fixed support. In this investigation carried out by reduction of bending stress and contact stress of circular fillet than standard fillet gear. Bending Stress of spur gear calculated Comparison of these examines are also carried out and assumed appropriately. A crack has been made to find the bending stress and contact stress of gears by using FEMAP software for calculating the performance.

TOOTH FILLET MODIFICATION



MATERIALS SELECTION:

Gray Cast Iron:

Poisson's ratio = 0.25
Young modulus = 165 GPa
Bulk modulus = 83.3 GPa
Yield Tensile Strength = 276 MPa
Ultimate Tensile Strength = 430 MPa
Ultimate Compressive Strength = 820MPa
Co-efficient of friction =1.1

SPECIFICATION OF SPUR GEAR

No of teeth N	= 18
Pressure angle θ	= 20°
Module m	= 5 mm
Pitch circle diameter D	= 90 mm
Out circle diameter D_O	= 100 mm
Base circle diameter D_b	= 84.6 mm
Diametral pitch D_p	= 0.2 mm
Circular pitch C_p	=15.705 mm
Clearance C	= 0.7854 mm
Addendum A_d	= 5 mm
Dedendum D_d	= 5.7854 mm
Dedendum circle diameter D_c	=78.4292 mm
Root diameter D_r	= 78.43 mm
Fillet radius (Standard Fillet)	=1.9635 mm
Fillet radius (Circular Fillet)	= 2.3 mm
Thickness of the tooth T	= 7.855 mm
Face width b	= 27 mm
Center distance between two gear A	= 90 mm

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DESIGN CALCULATION OF BENDING STRESS

Calculated based on the desired specification
Given above:

Speed (N) =1500rpm

P=20 kw

P=2*π*N*T/60

$$T = \frac{20000*60}{2*3.14*1500}$$

T=127323.95 N mm

T=F*(D/2)

$$F = \frac{127323.95*2}{90}$$

Tangential load F = 2829.42N

$F=\sigma_b * y * p_c * b$

Y=lewis form factor

= 0.154-(0.912/Z) for 20° full depth involute

=0.154-(0.912/18) =0.1033

P_c=circular pitch =15.70mm

b =width of gear tooth =27mm

$$\text{Bending stress } \sigma_b = \frac{2829.42}{0.1033*15.70*27}$$

σ_b =64.61 N/mm

DESIGN CALCULATION OF CONTACT STRESS

$$\sigma_c = 0.74 * \frac{i+1}{D}\sqrt{\frac{i+1}{ib}.E.[mt]}$$

Where,

$[Mt]=T*k_d*k$

=127323.95*1.3

=165521.13 Nmm

D=pitch circle diameter,

b=face width=27mm

i=gear ratio

T=Torque

K_d=1.3

k=1

E=young's modulus (Gray Cast Iron)

= 1.65 *10^5 N/mm²

$$\sigma_c = 0.74 * \frac{1+1}{90}\sqrt{\frac{1+1}{1*27}} * 1.65 * e^5 * [165521.13]$$

σ_c=739.64 N/mm²

ANALYTICAL METHOD CALCULATION:

Speed (rpm)	Torque (N-mm)	Bending Stress using Lewis's equation (N/mm²)	Contact Stress using Analytical method (N/mm²)
1000	190985.93	86.92	905.59
1500	127323.95	64.61	739.64
2000	95492.96	48.46	640.57
2500	76394.37	38.3	572.93

FINITE ELEMENT ANALYSIS OF SPUR GEAR

Finite Element Analysis is a computer-based numerical technique for Calculating the strength and behavior of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behavior and many other phenomena. It can be used to analyze either small or large-scale deflection under loading or applied displacement. It can analyze elastic deformation, or "permanently bent out of shape" plastic deformation. Basic procedure for spur gear analysis is following

- The solid model of spur gear with given dimension is modeled using the software FEMAP NX NASTRAN in Geometry option. This geometry exports to Static Structural (FEMAP).
- From the Engineering Data option applies properties of material. Material properties for the gear are given in the material models.
- From model option to select model material and mesh is generate with .5 mm element size.
- Then loads are defined at the suitable positions for Bending stress(inner surface is fixed and tip of the gear tooth corner load applied as lewis's equation)
- Loads are defined at the suitable positions for contact stress (displacement is fixed support at lower gear and frictionless, moment (Torque value) support at upper gear)
- After defining the loads. Solution is done by using solve option.
- From plot results maximum principle stress and contact stress is chosen to display the stress distribution in the Gear.

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Force analysis was carried out using by FEMAP. Comparison was made between the bending stress results of standard fillet gear and circular fillet gear. It was found that by increasing fillet radius from 1.95 mm (standard) to 2.25 mm (circular), the bending stress decreases for circular fillet at various speeds. Lewis equation results were used to verify the analyzed results. So by using Lewis equation, compare both standard and circular fillet design.

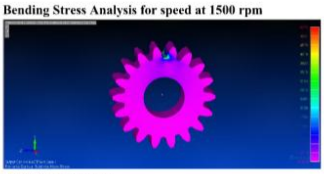
BENDING STRESS ANALYSIS

Bending Stress Analysis for speed at 1000 rpm


Circular fillet Gear

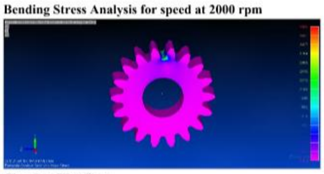

Standard fillet Gear

Bending Stress Analysis for speed at 1500 rpm


Circular fillet Gear

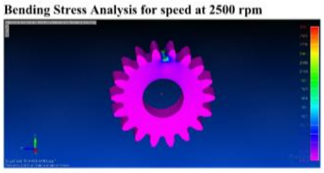

Standard fillet Gear

Bending Stress Analysis for speed at 2000 rpm


Circular fillet Gear


Standard fillet Gear

Bending Stress Analysis for speed at 2500 rpm


Circular fillet Gear

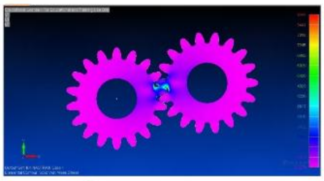

Standard fillet Gear

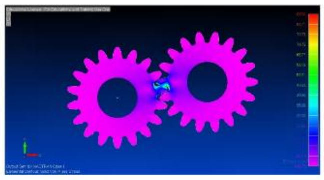
BENDING STRESS CALCULATION:

S.no	Speed (rpm)	Bending Stress by using Lewis's equation (N/mm²)	Bending Stress for Standard fillet gear (N/mm²)	Bending Stress for Circular fillet gear (N/mm²)
1	1000	86.92	89.06	79.09
2	1500	64.61	59.37	52.73
3	2000	48.46	44.53	39.55
4	2500	38.3	36.05	32.01

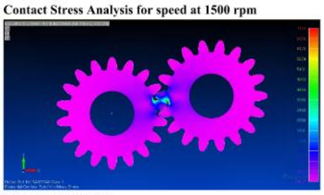
CONTACT STRESS ANALYSIS

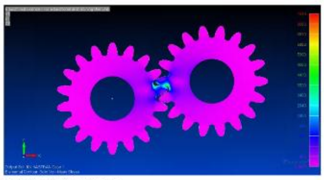
Contact Stress Analysis for speed at 1000 rpm


Circular fillet Gear

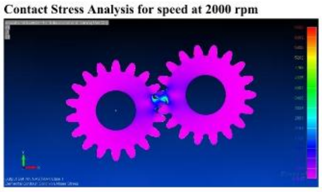

Standard fillet Gear

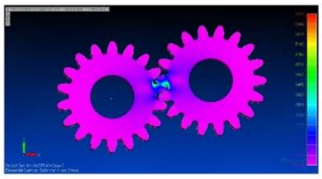
Contact Stress Analysis for speed at 1500 rpm


Circular fillet Gear

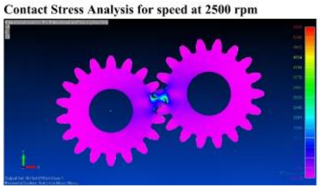

Standard fillet Gear

Contact Stress Analysis for speed at 2000 rpm


Circular fillet Gear


Standard fillet Gear

Contact Stress Analysis for speed at 2500 rpm


Circular fillet Gear


Standard fillet Gear

CONTACT STRESS CALCULATION:

S.no	Speed (rpm)	Contact Stress by using Lewis's equation (N/mm²)	Contact Stress for Standard fillet gear (N/mm²)	Contact Stress for Circular fillet gear (N/mm²)
1	1000	905.59	904.4	896.9
2	1500	739.64	747.4	734.9
3	2000	640.57	650.2	647.8
4	2500	572.93	566.8	560.6

RESULTS

For the given speed the contact and bending stresses are compared for the standard and circular fillets design. From FEMAP results shows that the bending and Contact stress values reduced in circular fillet gear compare to standard fillet. So this result indicates that the gears with circular root fillet intention gives better strength, reduction of contact stress and improve the fatigue life of gear material.

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