STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 11, Special Issue 8, 2023
DOI (Journal): 10.37591/JoPC

http://engineeringjournals.stmjournals.in/index.php/JoPC/index

Research JoPC

Effect of Fillet Radius on Bending Stress in Helical Gear using FEA

Hardial Singh[1,*], S.B. Gupta[2]

Abstract

A well-optimized change in root fillet radius could greatly benefit helical gear operation by providing a smoother transmission with less impact and noise. The fillet area of the gear root is an area of extensive bending stress concentration. An increase in fillet radius for helical gears is considered to minimise the bending stress at the gear tooth's base. This paper develops appropriate models of various gear tooth profiles of the helical gear with the same loading conditions to obtain the results using structural analysis (ANSYS) and validate the results with standard theoretical stress. This study is an attempt to evaluate the impact of the root fillet radius on bending stress, strain, and total deformation.

Keywords: Helical gear, fillet radius, ANSYS, KISSsoft, AGMA stress.

INTRODUCTION

One of the most effective method of transmitting smooth power and large load capacity between the shafts by means of helical gear. The gears are accurately designed and precisely manufactured with high strength materials so that they can withstand the work under different static and dynamic loading conditions. It also enhances the gearbox's efficiency and life. Helical gears should be made of materials that are strong, corrosion-resistant, lightweight, and long-lasting.

Bending stresses and contact stresses have been identified as key concerns for helical gear design. The root of the gear tooth is under a lot of bending stress, which causes the gear to bend. The problem can be precisely solved by profile optimization at the root of the helical gear. The KISSsoft software has been used in this study to design the gear and analyse the results in order to observe the effects of various aspects of design on stresses of the helical gear. Gidado A.Y [1] conducted the evaluation of the tooth bending stress on the gears with different face widths in increasing order. It found that the AGMA formulation reduced the bending stress on the helical gears. D. Deepak [2] evaluated the impact of contact stress and bending stress on the helical gear system using FEA and analytical techniques. Gambhir et al. [3] discovered that when the driving side pressure angle rises, the contact stress in asymmetric involute helical gears reduces. Bozca M [4] found that the carrying capacity of gears will be greater if the helix angel of the gear tooth is increased, thus the increase in total contact ratio will cause a reduction in contact and bending stress on the helical gear tooth. Sonali A. et al. [5] evaluated five different materials using FEA to determine the best material for the helical gear by examining the AGMA findings. Patil J. [6] discovered the impact of pressure angle and helix angle at the root of the helical gear tooth under dynamic conditions to reduce the bulk load of the gearbox of a vehicle. Miryam B. [7] conducted a comprehensive investigation of the tooth bending strength for the bending load capacity in order to identify the critical value of stress at the given critical load conditions for the helical gears. Sarkar G.T et al. [8]

*Author for Correspondence
Hardial Singh
E-mail Id: hsingh@ggn.amity.edu

[1]Assistant Professor, Department of Mechanical Engineering, Amity University Gurugram, Manesar, Haryana, India
[2]Professor, Department of Aerospace Engineering, Amity University Gurugram, Manesar, Haryana, India

Received Date: August 18, 2023
Accepted Date: September 12, 2023
Published Date: September 22, 2023

Citation: Hardial Singh, S.B. Gupta. Effect of Fillet Radius on Bending Stress in Helical Gear using FEA. Journal of Polymer & Composites. 2023; 11(Special Issue 8): S129–S136.

used FEA software to simulate the 3D model of the gear in order to determine the bending stress and compare it to the AGMA stress. Simon V. [9] studied various loading conditions and stress calculations in helical gear. The theory was established for a number of tooth and face widths that have the greatest impact on the load distribution parameters in helical gears. Jabbour T. [10] developed a theory for evaluating the stress distribution at the root of a helical gear and determining the maximum bending stress on each pair of helical gear due to line contact. Zeyin H. et al. [11] developed a mathematical model that incorporated real-world engineering to predict radiation noise in a gear system using a dynamic contact finite element method. Chunjiang He. [12] discussed the function of transmission errors and path of contact with misalignment between the gears. It shows the comparison of different properties between the curve-faced helical gear and straight-faced helical gear.

PROBLEM FORMULATION

The current research work can further be extended using FEA [13–18] by applying specific loading conditions with the change of the root fillet radius in order to get the optimum design of helical gear. In the current research work, the alloy steel material is used but the fillet radius varied from 0.5mm to 1.4 mm just to give a more precise and optimized design to the helical gear. KISSsoft software was used to develop the helical gear's involute profile. After that, a solid model was generated in SolidWorks software for CAD modelling. Structural analysis is done using Ansys.

DESIGN OF GEAR

To reduce the bending stress, the root fillet radius parameter has been introduced in the modification of the helical gear profile. KISSsoft software has been proposed for the design of helical gears as this software was specifically developed for the purpose of designing various gear tooth profiles. In this research work, the helical gear tooth profile has been developed with the help of KISSsoft software, and all specified parameters have been used to generate the involute tooth profile. Figure 1 depicts the tooth profile specifications of an involute helical gear for input into the software.

haP= Addendum
hfP= Dedendum
hprP= Protuberance height
αprP= Protuberance Angel
αKP= Ramp Angle
ρ_{fP}= Root fillet radius

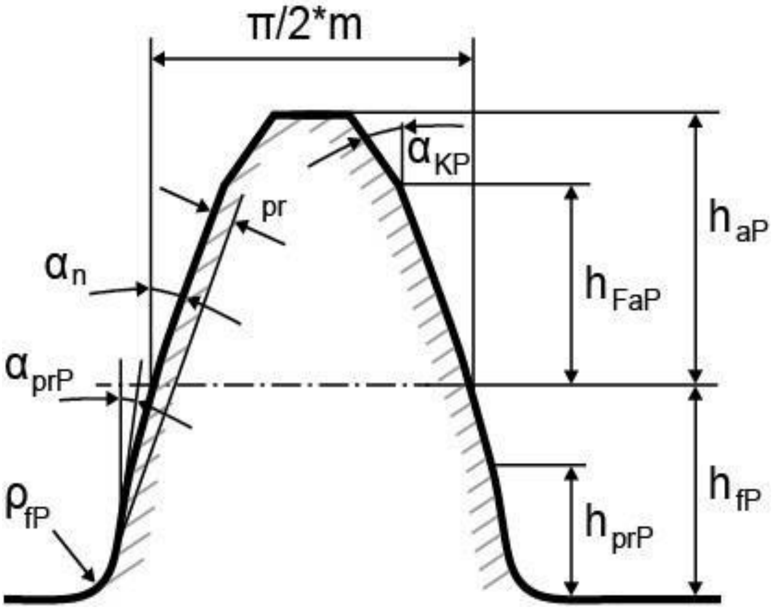

Figure 1. Tooth Profile.

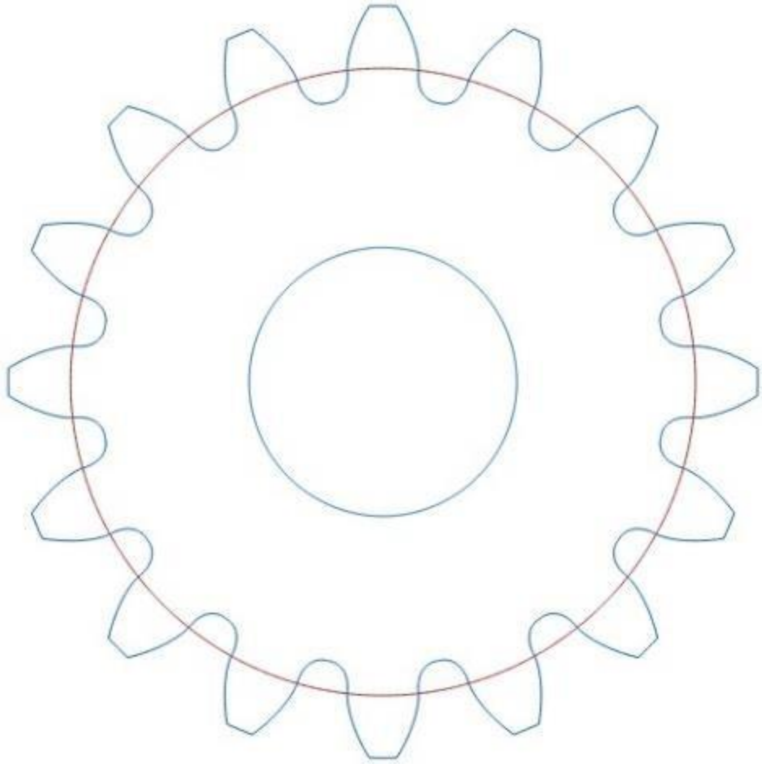

Figure 2. Involute profile.

The helical gear parameters, i.e., normal module, number of teeth, pitch circle diameter, helix angle, and pressure angle, are required for the design of the gear. The involute profile of a helical gear has been developed using the parameters determined by G Maitra [19].

Helical gear models were generated in KISSsoft modeller, where we assigned all parameters to its basic data part and used the reference profile part to execute all involute profiles of the helical gear for various root fillet radius profiles. Figure 2 depicts the generated involute profile. Table 1 lists the helical gear's geometric values, and Figure 3(i) depicts the generated solid model. Table 2 lists the gear's material properties.

Table 1. Parameters of the helical gear.

S/N	Variable Name	Description	Value (mm) (KW)
1	Z	No. of Teeth	16
2	M_n	Normal Module	3
3	D	Pitch circle Diameter	48
4	θ_p	Pressure Angle	20
5	β	Helix Angle	16
6	F	Face Width	40
7	h_{ap}	Addendum	3
8	h_{fp}	Dedendum	3.75
10	D_t	Tip Circle Diameter	56
11	D_r	Root Circle Diameter	42.5
12	C	Clearance	0.75

Table 2. Material Properties of the helical Gear.

S no	Description	Unit
1	Material Type	ALLOY STEEL-15Ni5Cr4Mo1
2	Working temperature	850-1150^{0}Cs
3	Tensile strength	1350 MPa
4	Yield strength	720 MPa
5	Density	7850 kg/m3
6	Young's modulus	210 GPa
7	Poisson ratio	0.3

AGMA (American Gear Manufacturing Association) has standardised gear tooth design for tooth contact stress and bending stress [20]. According to this theory, the bending stress on a tooth is calculated in terms of the tangential force acting on it. The force analysis is calculated by using the equations (1–5) on the basis of normal module, helix angle, number of teeth, gear speed, and force exerted on the pinion shaft.

1. Transverse modulus

$$M_t = \frac{M_n}{Cos\beta} \tag{1}$$

2. Pitch circle in mm

$$PCR=\frac{M_t \times Z}{2} \tag{2}$$

3. Torque in Nm

$$T=\frac{60P}{2\pi N} \tag{3}$$

4. Tangential Force (F_t) in N

$$F_t=\frac{T}{PCR} \tag{4}$$

5. AGMA Bending Stress Formulae:

$$\sigma_{b1} = \frac{F_t}{FM_nJ} \times K_v \times K_o(0.93 \times K_m) \tag{5}$$

The bending stress value is derived using the aforementioned equations (1-5) and various parameters, such as the overload factor (K_O), velocity factor (K_V), and load distribution factor (Km) are taken into account. The value of the overload factor (K_O) is calculated by the machinery-driven load and the kind of source power (heavy or light). The tangential velocity is used to determine the velocity factor, and the load distribution factor is chosen based on the loading parameters, such as mounting, clearance, deflection, and precision between gear drives. The torque has been computed to be 143.40 Nm based on a power of 22 KW and an input speed of 1465 rpm.

Using of CAE tools, the model's profiles have been imported to the SolidWorks Software to deals with the solid modelling feature of SolidWorks by varying root fillet radius of helical gears. The parameters have used for gear modelling as mentioned in Table 1. Fig. 3 (i) depicts a developed model of involute profile helical gear, which can be considered to be almost same with other solid models of helical gears due to small amount of change in fillet radius.

STATIC STRUCTURAL ANALYSIS

The developed helical gear model, shown in Figure 3(i), was imported in STEP format into ANSYS workbench's static structural module to analyse the bending stress on the helical gear. The helical gear material is applied as specified in Table 2. The Tetrahedron method is used to mesh this model, and the number of nodes and elements are listed in Table 3. Figure 3 (ii) depicts the finely mesh elements of a helical gear's 0.5 mm fillet, which have been meshed in the same way as the other five helical gears, as shown in Table 3.

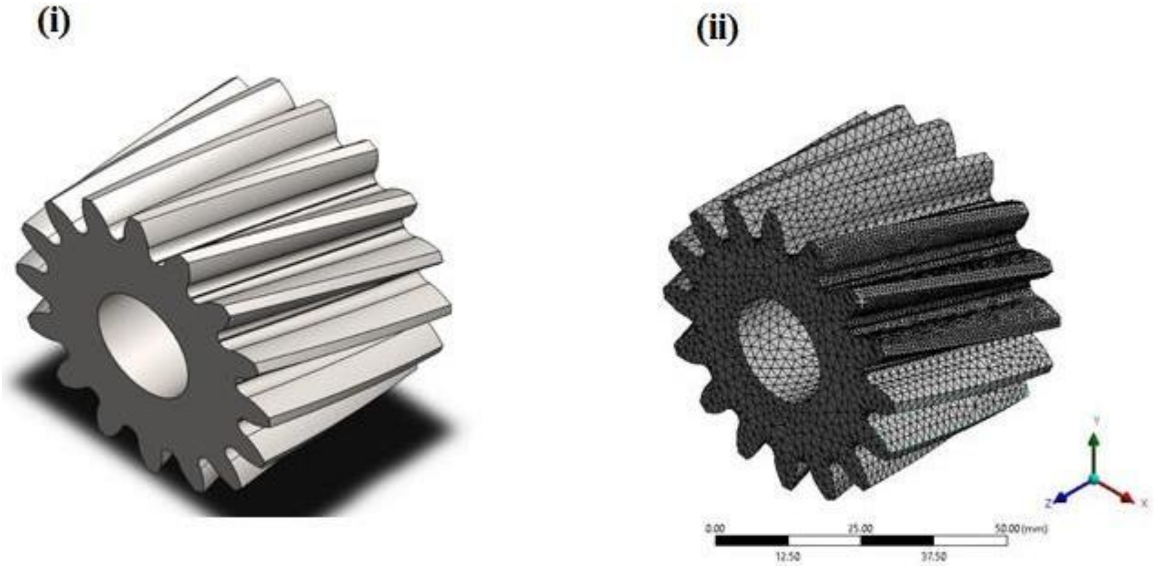

Figure 3. (i) CAD Model of Helical gear; (ii) Meshed Model of Helical gear.

Table 3. Number of nodes and elements of helical gear with various fillet radius.

ROOT FILLET RADIUS	0.5mm	0.7mm	1.0mm	1.2mm	1.4mm
NO. OF NODES	861550	275473	243297	274741	25547
NO. OF ELEMENTS	519828	172430	153866	173457	147562

RESULTS AND DISCUSSION

The helical gear’s results are represented as coloured figures and numerical data, with varying fillet radius for Von-Mises stresses, strains, and total deformations. The torque is considered to be 143.40 Nm as per the calculation of power 22 KW with an input speed of 1465 rpm. The Von-Mises stress Load distribution for a helical gear, where tangential force is 7975 N applied on the gear tooth of the model to establish the analysis outcomes for varying fillet radius of 0.5 mm, 0.7 mm, 1.0 mm, 1.2mm and 1.4 mm on helical gears. The red colour portions are identified to be maximum stress, strain and deformation area of the helical gear tooth.

As an illustration of these models can be observed that maximum Von-Mises stress developed on the helical gear is 196.83 N/mm^2 of 0.5 mm fillet radius in Figure 4 (i) and the minimum is found to be 169.14 N/mm^2 of 1.4 mm fillet radius in Figure 4 (ii). The Von-Mises strain developed on helical gear tooth which has found to be maximum of 0.00098 mm at 0.5 mm fillet radius in Figure 5 (i) and minimum of 0.00084 mm at 1.4 mm fillet radius in Figure 5 (ii). The Total deformation of a helical gear tooth can be observed to be maximum is 0.0089 mm at 0.5 mm fillet radius in Figure 6 (i) and minimum is found to be 0.0079 mm at 1.4 mm fillet radius in Figure 6 (ii).

Table 4. FEA results of the helical gears with different fillet radius.

Root fillet radius (mm)	0.5	0.7	1.0	1.2	*1.4*
Von-Mises stress (MPa)	196.83	191.28	188.2	172.62	*169.14*
Von-Mises strain (mm/mm)	0.00098	0.00095	0.00094	0.00086	*0.00084*
Total Deformation (mm)	*0.0089*	*0.0090*	*0.0092*	*0.0080*	*0.0079*

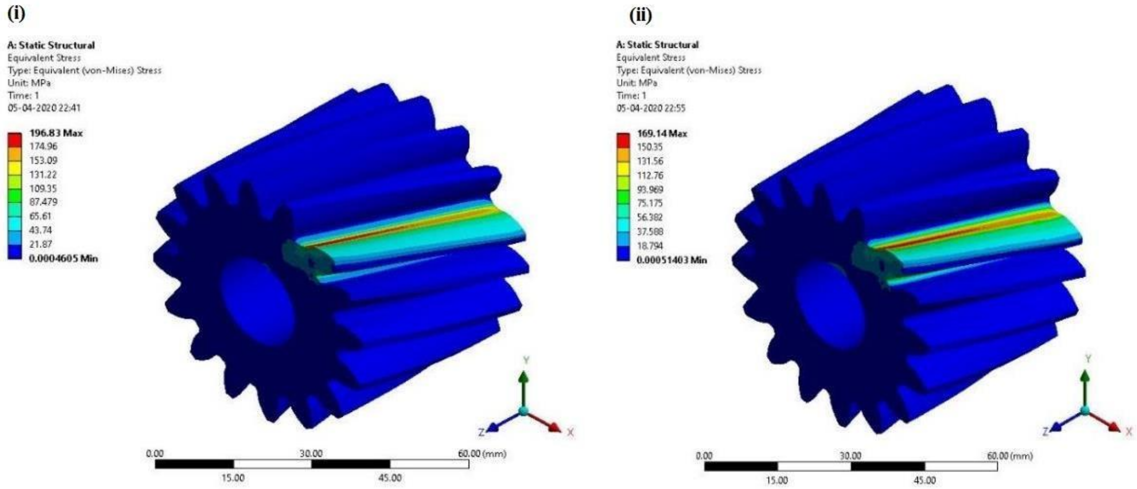

Figure 4. (i) Von-Mises stress at root fillet radius of 0.5 mm; (ii) Von-Mises stress at root fillet radius of 1.4 mm.

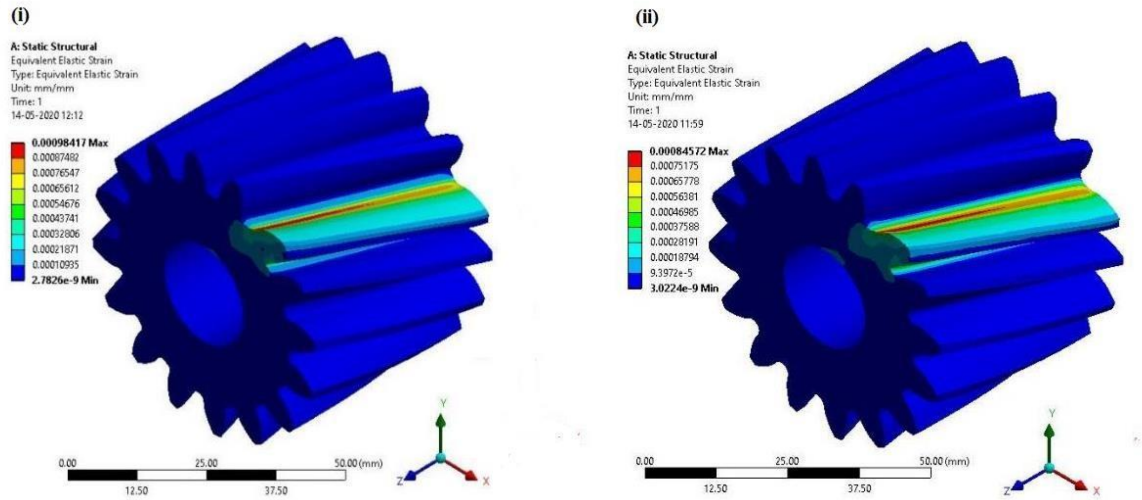

Figure 5. (i) Von-Mises strain at root fillet radius of 0.5 mm; (ii) Von-Mises strain at root fillet radius of 1.4 mm.

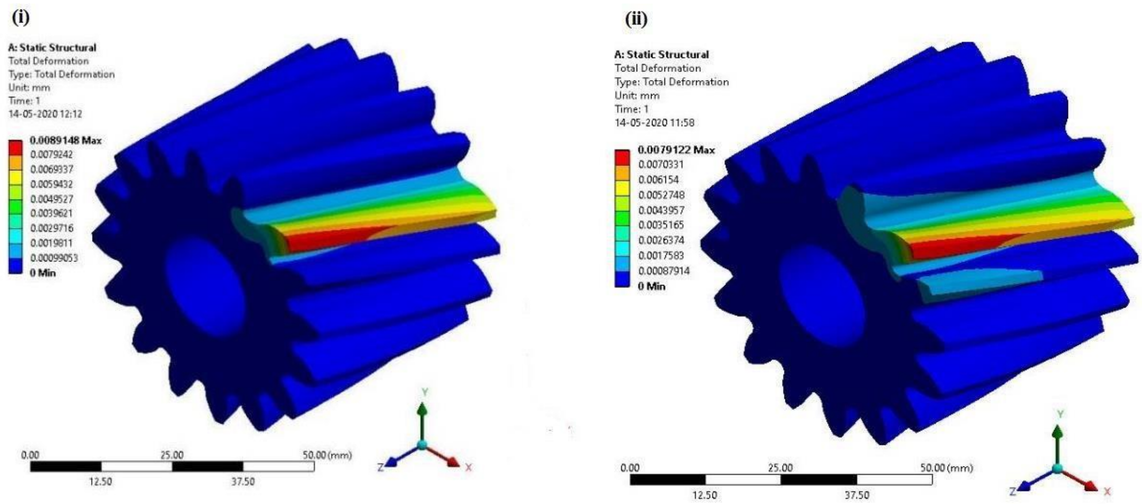

Figure 6. (i) Total deformation at root fillet radius of 0.5 mm; (ii) Total deformation at root fillet radius of 1.4 mm

The observation can be drawn from the Table 4 that the root fillet radius increased from 0.5 mm to 1.4 mm with results in a reduction of Von-mises stress from 196.83 N/mm^2 to 169.14 N/mm^2 which is 14.06% of the decrease in Von-Mises stress. The Von-mises strain also decreased from 0.00098 to 0.00084 which is about to decrease in 14.28% of Von-Mises strain and the Total deformation has decreased from 0.0089 mm to 0.0079mm about to decrease in 11.23% with regarding maximum deformation. It has been observed that more the fillet radius, less the impact of force to be found at helical gear tooth.

In every case, the bending stress is less than the material's yield stress. Comparison of maximum bending stress obtained by AGMA with the maximum bending stress is obtained by ANSYS software as mentioned in Table 5. It shows that percentage error to be less than 10%.

Table 5. Comparison of analytical and numerical result.

S/N	Face width [mm]	AGMA [Mpa]	ANSYS [Mpa]	Percentage Differences [%]
1	40mm	209.02	196.83	6

The increase in value of fillet radius is restrained by the fact that there should not be any interference between gears when teeth are in contact. The interference is likely not to happen when the fillet radius is too high. When the gear is cut with a normal gear shaper, the cutting tool will interfere with the area of the tooth below the base circle and will cut away the interfering material. This will result in undercutting which weakens the tooth by removing material. The fillet radius increments have a positive effect on the design parameters of helical gears but it is restrained by interference and undercutting. It is evident from Table 4 it shows that with the increase in fillet radius, the Von- Mises stress goes on decreasing from the magnitude of 196 MPa to 169MPa.

CONCLUSION

The results of the performed research work allow the following conclusions to be drawn:

- A relationship has been found between the amount of root fillet radius and Von-Mises stress and strain in the helical gear.
- Von-Mises stress and strain in symmetric helical gears decrease with an increase in the root fillet radius of the helical gear as mentioned in Table 4.
- The maximum reduction in bending stress concentration occurs with a higher root fillet radius of 1.4 mm, with a 15.10% reduction as per equation (5).
- The total deformation decreases with an increase in root fillet radius, which can be observed from simulation results.

REFERENCES

1. Gidado AY, Muhammad I, Umar AA. Design, modeling and analysis of helical gear according bending strength using AGMA and ANSYS. Int'l Journal of Engineering Trends and Technology. 2014 Feb;8(9).
2. Deepak D. Load Sharing Based Analysis of Helical Gear using Finite Element Analysis Method. SSRG International Journal of Mechanical Engineering, Volume 4 Issue 4–April 2017.
3. Gambhir J, Kumar P, Aggarwal B, Arya H. Effect of Drive Side Pressure Angle on Load Carrying Capacity of Asymmetric Involute Helical Gear, IJAPIE, 57–61, 2018.
4. Bozca, Mehmet. "Helix angle effect on the helical gear load carrying capacity." World Journal of Engineering and Technology 6, no. 04 825, 2018.
5. Mote MS, Gaur AV, Gujale MA. Design and FEM analysis of helical gear. IJERAT, Journal Impact Factor. 2018 Apr; 2:14.

6. Patil PJ, Patil M, Joshi K. Investigating the effect of helix angle and pressure angle on bending stress in helical gear under dynamic state. World Journal of Engineering. 2018 Aug 6;15(4):478-88.
7. Sanchez MB, Pedrero JI, Pleguezuelos M. Critical stress and load conditions for bending calculations of involute spur and helical gears. International Journal of Fatigue. 2013 Mar 1;48:28-38.
8. Sarkar, Govind T., Yogesh L. Yenarkar, and Dipak V. Bhope. Stress analysis of helical gear by finite element method. International Journal of mechanical Engineering and robotics research, 2278-0149, 2013.
9. Simon, V. "Load and stress distributions in spur and helical gears.*J. Mech., Trans., and Automation. 1988, 10(2): 197-202.*
10. Jabbour T, Asmar G. Tooth stress calculation of metal spur and helical gears. Mechanism and Machine Theory. 2015 Oct 1;92:375-90.
11. Zeyin H, Tengjiao L, Tianhong L, Tao D, Qiguo H. Parametric modeling and contact analysis of helical gears with modifications. Journal of Mechanical Science and Technology. 2016 Nov;30:4859-67.
12. He C, Lin C. Analysis of loaded characteristics of helical curve face gear. Mechanism and Machine Theory. 2017 Sep 1;115:267-82.
13. Krup Kumar HS. Increasing Bending Strength of Aluminium Silicon Carbide Metal Matrix Composite Spur Gear by Increasing Fillet Radius. IJRASET, Volume 6 Issue V, May 2018.
14. Pradhan S, Singh H, Parkarsha O. Bending Strength Analysis of Involute Helical Gear Using FEA Software. InAdvances in Engineering Design: Select Proceedings of FLAME 2020 2021 (pp. 651-660). Springer Singapore.
15. Singh H, Kumar D. Effect of face width of spur gear on bending stress using AGMA and ANSYS. International Journal for Simulation and Multidisciplinary Design Optimization. 2020;11:23.
16. Gupta A, Sharma A, Singh H, Rajoria CS. Computational and statistical analysis on the U-tube heat exchanger with different passes configuration: Taguchi method. Heat Transfer. 2021 Mar;50(2):1712-32.
17. Singh H, Bhushan G. Finite Element Analysis of a Front Lower Control Arm of LCV Using Radioss Linear. InNational conference in NCAMT-2012 held in NITTTR, Chandigarh, NITTTR, Chandigarh 2016.
18. Parkash O, Singh H. Optimization of Connecting Rod of U650 Tractor Using ANSYS. InNational conference in NCAMT-2013 held in NITTTR, Chandigarh, NITTTR, Chandigarh.
19. Gitin M Maitra, "Handbook of Gear Design", 2nd Edition, 1994.
20. Shigley, Joseph Edward. Shigley's mechanical engineering design. Tata McGraw-Hill

