Bending Strength Analysis of Involute Helical Gear Using FEA Software

Shashikant Pradhan, Hardial Singh, and Om Parkarsha

Abstract This paper investigates the simulation of helical gears with varying face width as per the applied transverse load to prevent the bending failure in the power transmission system. The symmetric involute profile of the helical gear has been established in KISSsoft software for more accurate precision in involute profile as it is a Gearbox designing software with a number of implementations of mechanical engineering. The drive side face of the helical gear has been introduced to simulate the meshing properties with fine elements and stress analysis with the use of FEA software, ANSYS 16.0. The numerical computation procedure for maximum bending stress on gear tooth has been estimated with concerning to the assistance of AGMA equations to find out the theoretical results of bending stress analysis which further validate with the simulation results to identify the percentage of error from the analysis. This paper also investigates the bending fatigue failure of alloy steel material with applied increasing load of solid models to find out the yielding point of the material.

Keywords Helical gear · AGMA stress · KISSsoft · SolidWorks · ANSYS

1 Introduction

Gear plays a vital role in transmitting power between the shafts. The design and manufacture of precision gears are made from high strength of materials, so that they will not miss carrying under static and dynamic loading during normal running conditions. It also succeeds as an improvement towards the function of gear speed and efficiency of the gearbox. The material of helical gears should be robust, corrosion resistance, lightweighted and should be durable for long period. The bending stresses and contact stresses have been found to be some of the major matter of concern for the designing of a helical gear pair. The deformation of helical gear can be perceived due to extreme bending stress condition at the root of the gear tooth. The problem can

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be precisely solved on the minimization of bending stress and contact stress through modified geometry of the gear tooth in highly accurate gear designing software.

Gidado [1] performed the analysis of bending stress of the symmetric helical gear with corresponding to dissimilar face width gears with reference to the AGAM formulation. Deepak [2] investigated the characteristics of a helical gear system mainly focused on bending and contact stress using analytical and FEA. Gambhir et al. [3] found that as the drive side pressure angle increases, the contact stress on teeth reduces as compared to asymmetric involute helical gear. Bozca [4] estimated the gear load carrying capacity would be more if the helix angle of the gear tooth is more, and as a result, the increasing total contact ratio will cause the reduction in bending and contact stress on the helical tooth. Sonali et al. [5] considered five different gear materials to simulate the FEA software to find out the better material for the helical gear, while comparing with the numerical AGMA equation results. Patil [6] presented the work on study of effect of pressure angle and helix angle at root of helical gear tooth under dynamic state to reduce total bulk of the gear box. Miryam [7] obtained the critical value of stress and critical load condition have been obtained, and a complete analysis of the tooth bending strength has been carried out for bending load capacity of helical gear. Sarkar et al. [8] simulated the 3D model of gear in FEA software to find out the bending stress and compare with the AGMA stress. Simon [9] obtained results for the calculation of load and stress distribution in helical gear is developed. The number of tooth and the face width has the strongest effects on the load distribution factors. Jabbour [10] presented a method to calculate the distribution of the stress at the tooth root and of the bending stress is maximum on each line of a pair helical gear. Zeyin et al. [11] approached a mathematical model with practical engineering in which dynamic contact finite element method has been used for radiation noise prediction of gear system. He [12] covered the contact path and the function of transmission errors with misalignment, included the comparison of helical curve face gear and straight curve face gear.

2 Design of Gear

The extremely intricate part of any gear model is the involute profile of its teeth, which has been optimized with the approach of the gear design software KISSsoft modeller which provides all valid calculation of parameters such as profile shift coefficient, tooth thickness allowances, tolerances, backlash, clearances, and factors. In addition to validate the calculation with respect to required standards (ISO, DIN, AGMA, VDI) are available, it also offers various optimization of design and modification functions for better results. The integrated calculation of KISSsoft software provides the precise involute profile of gear tooth, and gear parameters are calculated based on [13] and represent the involute profile in Fig. 1. The ferrous material such type of having ALLOY STEEL (15Ni5Cr4Mo1) material properties of the gear is considered in Table 1.

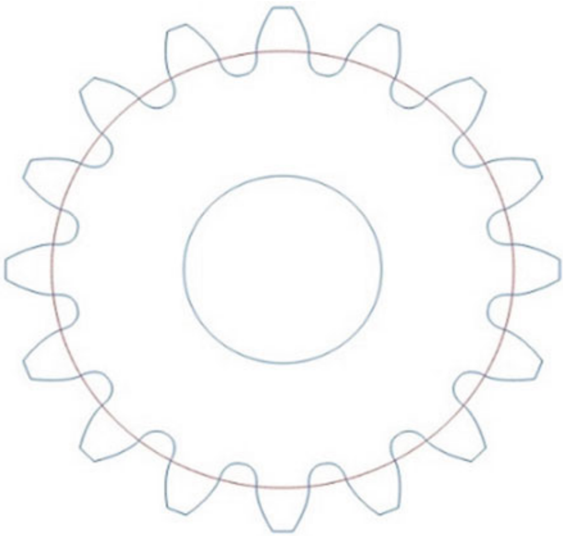

Fig. 1 Involute profile of helical gear

Table 1 Material properties of gear

S. No.	Description	Unit
1	Material type	ALLOY STEEL–15Ni5Cr4Mo1
2	Working temperature	850–1150
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

To move along with the calculation of the helical gear parameters, the power of 22 KW with input speed of 1465 RPM has been considered to calibrate values of the helical gear which are tabulated in Table 2.

American Gear Manufacturing Association (AGMA) [14] stress theories have been established for calculation methodology for the tooth bending stress. An theoretical approach has been subjected to the parameters like the normal module, helix angle, gear teeth, speed of the gear, and power acting on the pinion shaft to compute the bending stress which depends upon the tangential force acting on the tooth. The theoretical values could be calculated as follows:

Transverse modulus (M_t):

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

Table 2 Characteristics of helical gears

Variable name	Description	Value
Z	No. of teeth	16
M_n	Normal module	3
θ_p	Pressure angle	20
β	Helix angle	16
F	Face width	40
A	Addendum	3
B	Dedendum	3.75
D_t	Tip circle diameter	56
D_r	Root circle diameter	42.5

Pitch circle radius (PCR):

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

Tangential force (F_t):

$$F_t = \frac{T}{\text{PCR}} \tag{3}$$

AGMA bending stress formulae:

$$\sigma_{b1} = \frac{F_t}{F M_n J} \times K_v \times K_o(0.93 \times K_m) \tag{4}$$

To calculate the theoretical value of bending stress, Eqs. (1), (2), and (3) have been combined to evaluate the Eq. (4), and all the necessary factors have calculated from [15] with considering all type of graphs with various limitation such as overload factor (K_o) defined for uniform driven machinery with light shock source of power, velocity factor (K_v) considered after calculating the tangential velocity from the velocity factor graph, load distribution factor (K_m) considered according to loading properties of accurate mounting, small clearance, minimum deflection and precision between gear drives. Figure 2. shows the solid model of the helical gear having 40 mm face width generated in SolidWorks 2016 software.

3 Static Structural Analysis

In order to perform bending stress analysis on the helical gear assembly, a developed model of helical gear has shown in Fig. 2 and proceeded for simulation aside with distinctive face width to Ansys workbench in the static structural module in the

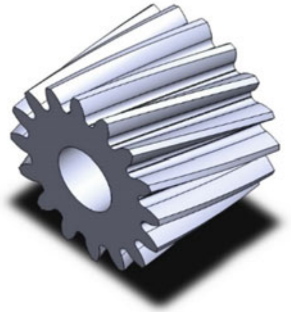

Fig. 2 CAD model of helical gear

format of STEP. The 3D model has meshed in the static structural module of Ansys software. In this meshing, tetrahedron method has followed with fine quality of division in which the number of nodes and elements are shown in Table 3, and Fig. 3 shows fine-meshed elements of the 40 mm face width alike other four helical gears have meshed as like as the information given in Table 3.

From the above Figures, it is found out that maximum bending stress occurs at helical gear having 40 mm face width in Fig. 4 represents the von Mises stress of 208.92 N/mm^2, Fig. 5 represents the value of 181.55 N/mm^2, Fig. 6 represents the

Table 3 Number of nodes and element of varying face width of helical gear

Face width (mm)	40	45	50	55	60
No. of nodes	162,955	194,827	202,580	222,793	328,874
No. of elements	105,292	115,855	125,362	144,687	208,651

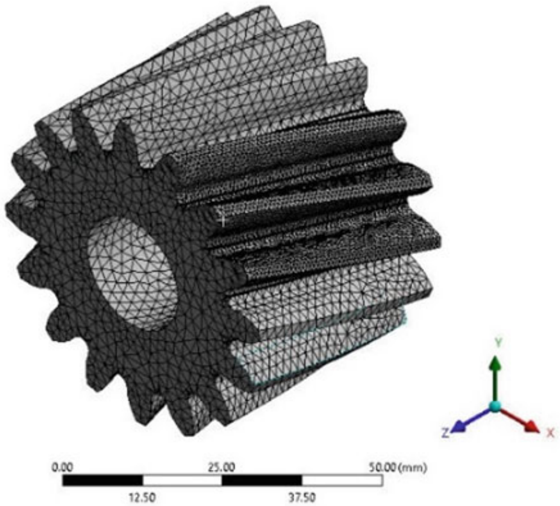

Fig. 3 Meshed model of helical gear

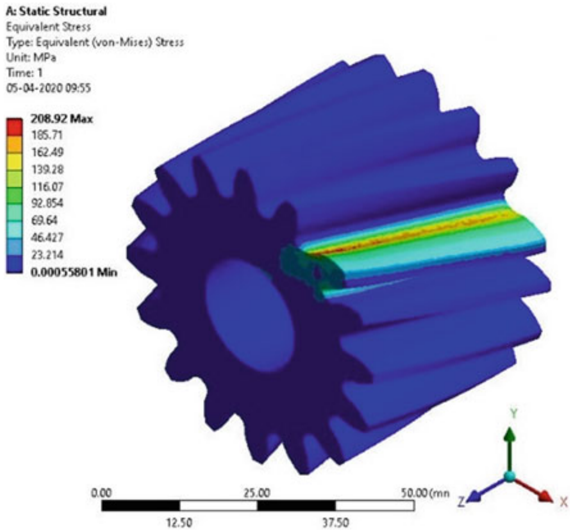

Fig. 4 Gear having face width 40 mm

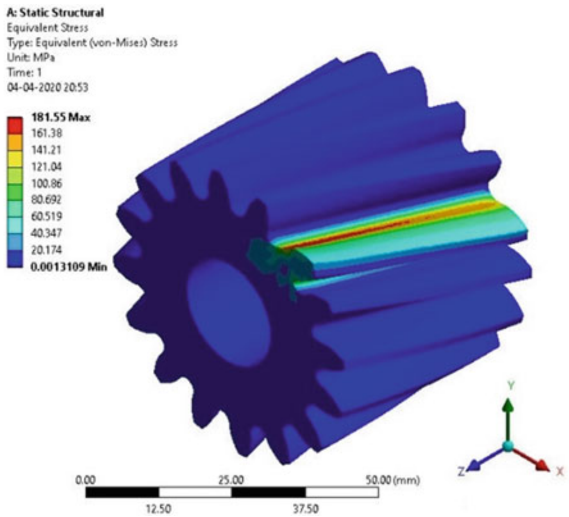

Fig. 5 Gear having face width 45 mm

value of 163.45 N/mm^2, Fig. 7 represents the values of 142.7 N/mm^2, and Fig. 8 represents the value of 134.75 N/mm^2, and as a result, it found to be von Mises stress is occurring in decreasing order.

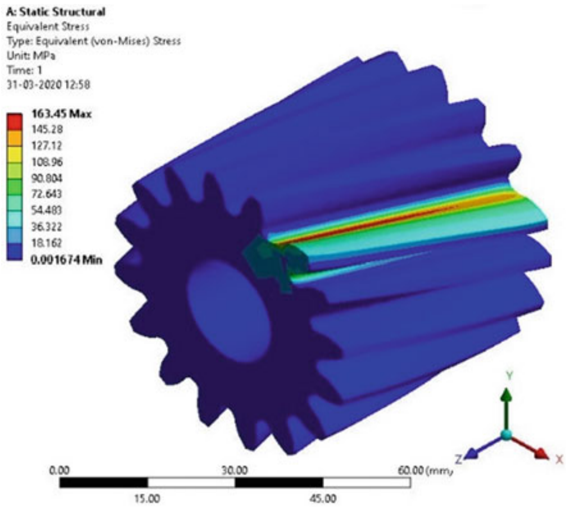

Fig. 6 Gear having face width 50 mm

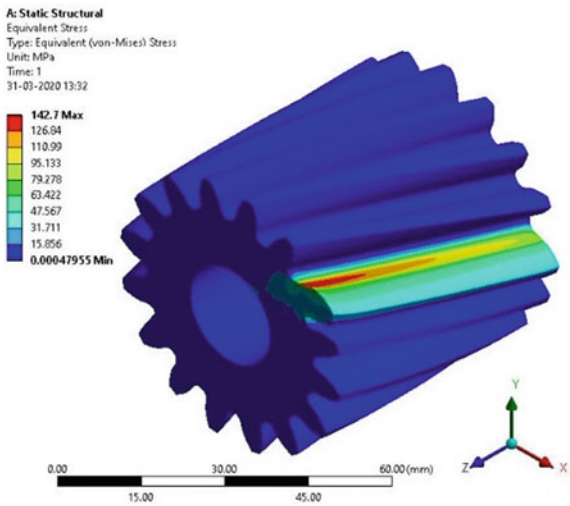

Fig. 7 Gear having face width 55 mm

4 Results and Discussion

The use of KISSsoft software provides reports, accurate strength calculation, and all valid calculation of parameters to modify the involute profile of helical gear. KISSsoft provides reports and accurate strength calculation of the design, and the comparison of results and percentage of error could be noticeable in both AGMA and Ansys values from the simulation of helical gear in Table 4.

The above Table 4 describes that the percentage of error at 55 mm is maximum which can be observed to be 6.12%. The reduction of von Mises stress can be detected

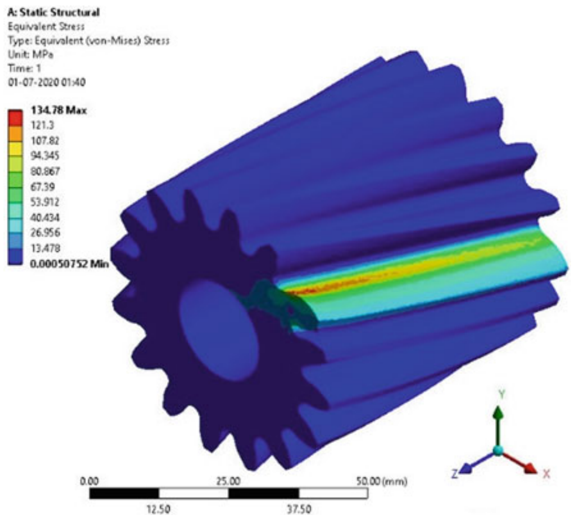

Fig. 8 Gear having face width 60 mm

Table 4 Bending stress value for existing design

S/No.	Face width [mm]	AGMA [Mpa]	Ansys [Mpa]	Differences [%]
1	40	209.02	208.92	2.51
2	45	185.79	181.55	2.28
3	50	167.21	163.45	2.24
4	55	152.01	142.7	6.12
5	60	139.34	134.78	3.27

from face width 40–60 mm with a decrease of bending stress of 76.62 N/mm^2, while it has seen that gear with higher face width is convenient for any steady tangential load and speed.

Figure 9 shows the graph between the bending stress (Mpa) and face width (mm). From the graph, it can be seen that bending stress has reduced from 208.92 to 132.30 N/mm^2 due to the increasing amount in face width from 40 to 60 mm, as per the results 33.33% of stress reduction in theoretical approach (AGMA) and 35.48% in analytical values (Ansys). The computational accuracy found 2.31%, and overall reduction in error found to be 3.27%. It also defines a reciprocal relation between the bending stress and the face width.

5 Conclusion

The KISSsoft software was persuaded to procure the more accurate involute profile for the helical gear in Fig. 1 as it is specifically used for designing of the gearbox,

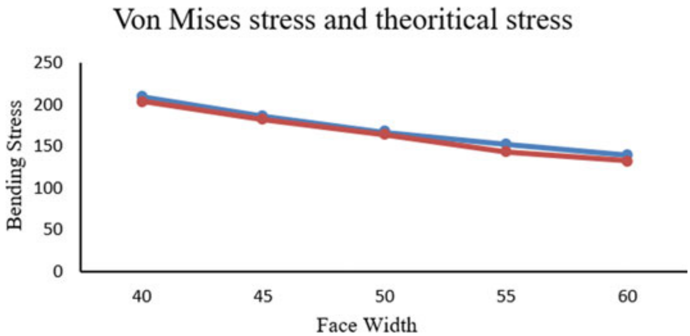

Fig. 9 Comparison of AGMA stress and Ansys stress at 5975 N of tangential load with increase in face width

onwards CAD models have been improvised in Ansys Workbench for simulation, which comprehends several assumptions and simplifications. The conclusion drawn from the simulated results is as summarized below:

- In finite element analysis, very fine-meshed has been the result of high accuracy in simulation values with accurate bending stress of the helical gears.
- The effect of increasing face width in symmetric helical gear reduces the stress concentration at the critical area of the gear.
- The maximum bending load distribution observed to be root fillet area of drive face, and the reduction in bending stress (Ansys) of helical gear creates to be 35.48% at 60 mm face width of the helical gear.
- According the course of action of this study, the design and modification of symmetric involute helical gear could be considered as an economical procedure for future aspects and optimization in reality.

References

1. Gidado AY, Muhammad I, Umar AA (2014) Design, modeling and analysis of helical gear according bending strength using AGMA and ANSYS. Int J Eng Trends Technol (IJETT). ISSN: 2231-5381
2. Deepak D Load sharing based analysis of helical gear using finite element analysis method
3. Gambhir J et al Effect of drive side pressure angle on load carrying capacity of asymmetric involute helical gear
4. Bozca M (2018) Helix angle effect on the helical gear load carrying capacity. World J Eng Technol 6(04):825
5. Sonali A et al Design and FEM analysis of helical gear
6. Patil PJ, Patil M, Joshi K (2018) Investigating the effect of helix angle and pressure angle on bending stress in helical gear under dynamic state. World J Eng
7. Sanchez MB, Pedrero JI, Pleguezuelos M (2013) Critical stress and load conditions for bending calculations of involute spur and helical gears. Int J Fatigue 48:28–38

8. Sarkar GT, Yenarkar YL, Bhope DV (2013) Stress analysis of helical gear by finite element method. Int J Mech Eng Robot Res. ISSN: 2278-0149
9. Simon V (1988) Load and stress distributions in spur and helical gears. pp 197–202
10. Jabbour T, Asmar G (2015) Tooth stress calculation of metal spur and helical gears. Mech Mach Theory 92:375–390
11. Zeyin H et al (2016) Parametric modeling and contact analysis of helical gears with modifications. J Mech Sci Technol 30(11):4859–4867
12. He C, Lin C (2017) Analysis of loaded characteristics of helical curve face gear. Mech Mach Theory 115:267–282
13. Maitra GM Handbook of gear design, 2nd edn
14. ISOigearistandards. https://www.iso.org/
15. Shigley JE (2011) Shigley's mechanical engineering design. Tata McGraw-Hill Education