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Comparative Study of Stress Analysis of Helical Gear Using AGMA Standards and FEM

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Abstract

Gearing is one of the most effective methods for transmitting power and rotary motion from the source to its application with or without change of speed or direction. The bending and surface strength of the gear tooth are considered to be one of the main contributors for the failure of the gear in a gear set. Thus, determination of stresses has become popular as an area of research on gears to minimize or to reduce the failures and for optimal design of gears. This thesis investigates the characteristics of an involute helical gear system mainly focused on bending and contact stresses using analytical and finite element analysis. To estimate the bending stress, three-dimensional solid models for different number of teeth are generated by Pro/Engineer that is a powerful and modern solid modeling software and the numerical solution is done by ANSYS, which is a finite element analysis package. The analytical investigation is based on Lewis stress formula. This thesis also considers the study of contact stresses induced between two gears. Present method of calculating gear contact stress uses Hertz's equation. To determine the contact stresses between two mating gears the analysis is carried out on the equivalent contacting cylinders. The results obtained from ANSYS are presented and compared with theoretical values.

Face width and helix angle are important geometrical parameters in determining the state of stresses during the design of gears. Thus, in this work a parametric study is conducted by varying the face width and helix angle to study their effect on the bending stress of helical gear.

Keywords: Involute, helical gear, stresses, optimization, finite element analysis.

Introduction

The crucial requirement of effective power transmission in various machines, automobiles, elevators, generators, etc. has created an increasing demand for more accurate analysis of the characteristics of gear systems. For instance in automobile industry highly reliable and lightweight gears are essential. Furthermore the best way to diminution of noise in engine requires the fabrication of silence gear system. Helical gears are currently being used increasingly as a power transmitting gear owing to their relatively smooth and silent operation, large load carrying capacity and higher operating speed. Designing highly loaded helical gears for power transmission systems that are good in strength and low level in noise necessitate suitable analysis methods that can easily be put into practice and also give useful information on contact and bending stresses [1]. Vijayaragan and Ganesan [2] presented a static analysis of composite helical gears system using three dimensional finite element methods to study the displacements and stresses at various points on a helical gear tooth. Rao and Muthuveerappan [3] explained about the geometry of helical gears by simple mathematical equations, the load distribution for various positions of the contact line and the stress analysis of helical gears using the three dimensional finite element methods. Cheng and Tsay [4] investigate the contact and the bending stresses of helical gear set with localized bearing contact by means of finite element analysis (FEA). Face width and helix angle are important geometrical parameters in determining the state of stresses during the design of gears. Nagesh Alemu [5] conducted a parametric study by varying the -face width and helix angle to study their effect on the bending stress of helical gear. Ali Raad Hassan [6] has considered a pair of spur gear teeth and contact stress has been analyzed in different contact positions of matting gears during rotation. Hedlund and Lehtovaara presented a study, focuses mainly on the modeling of helical gear contact with tooth deflection.

Gear Terminology

Pitch circle diameter: The pitch circle diameter is the diameter of pitch circle. Normally, the size of the gear is usually specified by pitch circle diameter.

Addendum: The Addendum is the radial distance between the pitch and addendum circles. Addendum indicates the height of tooth above the pitch circle.
Dedendum: The dedendum is the radial distance between pitch and the dedendum circles. Dedendum indicates the depth of the tooth below the pitch circle.
Module: It is the ratio of pitch circle diameter to the number of teeth.
Pressure angle: It is the angle that the line of action makes with the common tangent to the pitch circles.
Number of teeth: Indicates the number of teeth on the gear.
Helix angle: It is a constant angle made by helices with the axis of rotation.

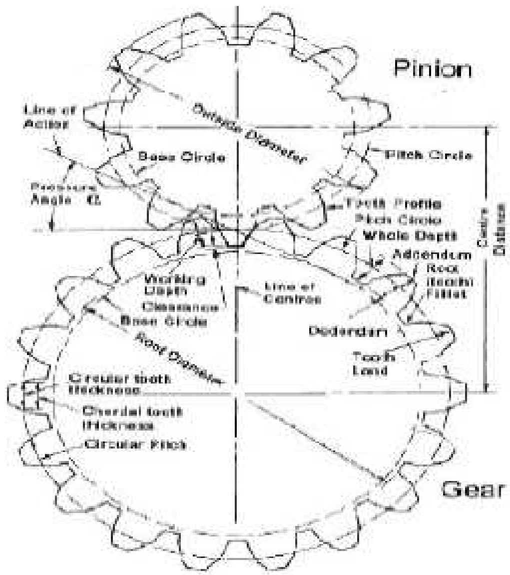


Figure 1 Gear terminology

Involute Gear Tooth Profile

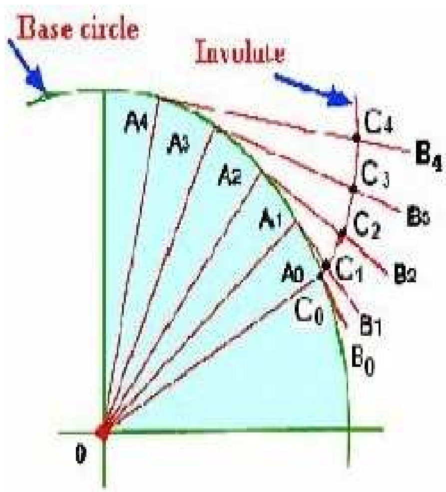


Figure 2: Involute gear tooth profile

Involute is the path generated by the end of a thread as it unwinds from a reel. In order to understand what is involute, imagine a reel with thread wound in the clockwise direction as in Fig.2. Tie a knot at the end of the thread. In the initial position, the thread is at BO with knot on the reel at CO. Keeping the reel stationary, pull the thread and unwind it to position B1.The knot now moves from CO to C1. If the thread is unwound to position B2 the knot moves to C2 position. In repeated unwinding, the knot thread occupies position B3, B4while the knot moves to C3,C4 positions. Connect these points CO to C4 by a smooth curve, the profile obtained is nothing but an involute.

CAD Modeling OF Helical Gear Using PRO/E 5.0

3D Wheel Model:

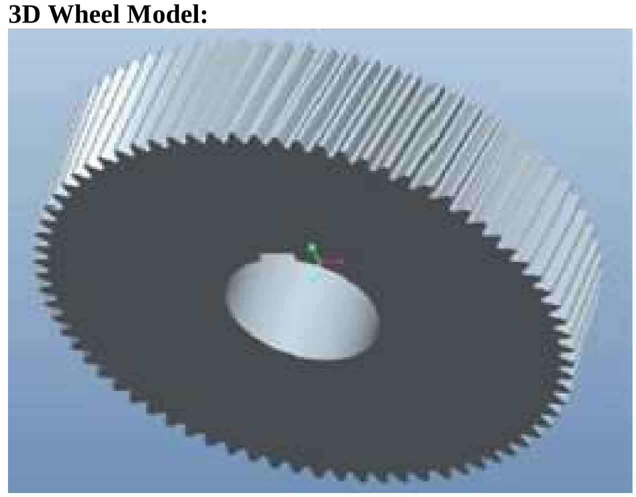


Figure 3 : Wheel model

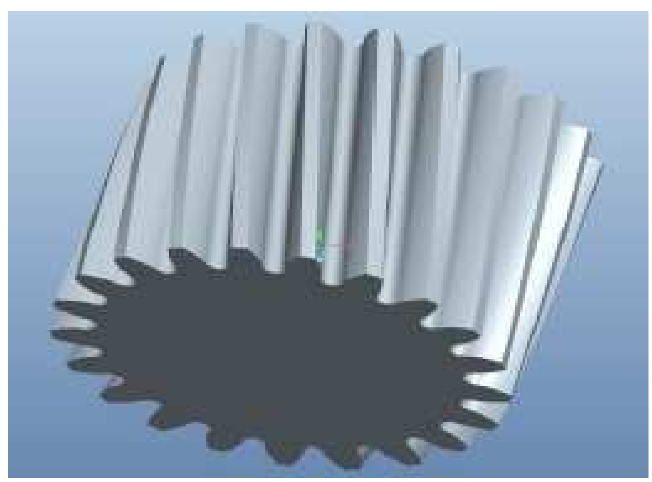


Figure 4

3D Wheel and Pinion Assembly of Helical Gear:-

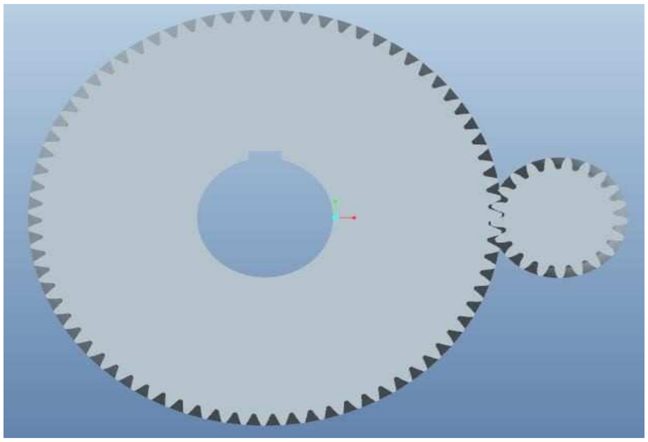


Figure 5 : Helical gear assembly

FEA of Gear Tooth Using Ansys Workbench 11.1

The following steps are used in the solution procedure using ANSYS Workbench 11.1

1. **Finite Element Formulation**

For three-dimensional stress analysis solid elements are useful for the solution of problems. These solid elements are broadly grouped under tetrahedral, triangular and hexahedral family elements.

In this thesis, the three-dimensional eight noded solid element is chosen from hexahedral family for the element representation that uses for three dimensional analysis based isoparametric formulation. This is because for the analysis of some components of complex shapes involving curved boundaries or surfaces, like helical gears simple triangular or rectangular elements are no longer sufficient.

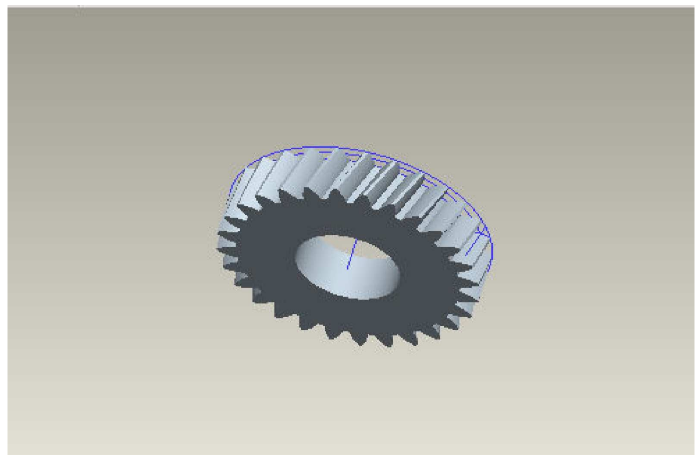
2. **Solid Modeling**

Solid Modeling is geometrical representation of a real object without losing information the real object would have. It has volume and therefore, if someone provides a value for density of the material, it will have mass and inertia. Unlike the surface model, if one makes a hole or cut in a solid model, a new surface is automatically created and the model recognizes which side of the surface is solid material. The most useful thing about solid modeling is that it is impossible to create a computer model that is ambiguous or physically non-realizable

General Procedures to Create an Involute Curve

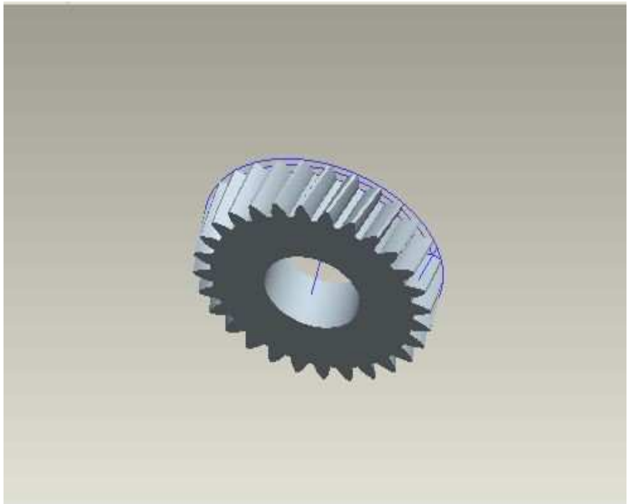
The sequence of procedures employed to generate the involute curve are illustrated as follows: -

1. Set up the geometric parameters
    - Number of teeth
    - Diametral Pitch
    - Pressure angle
    - Pitch diameter
    - Face width
    - Helix angle
2. Create the basic geometry such as addendum, dedendum and pitch circles in support of the gear tooth.
3. Define the involute tooth profile with datum curve by equation using cylindrical coordinate system.
4. Create the tooth solid feature with a cut and extrusion. Additional helical datum curves are also required in this step to sweep helical gear teeth.
5. Pattern the tooth around the centre line axis.



Number of teeth	28
Diametral pitch (p) [mm]	152.4
Pressure angle	25 degree
Face width [mm]	25.4
Addendum [mm]	1/p
Dedendum [mm]	1.25/p
Helix angle	20 degree

Solid model of helical gear generated by Pro/Engineer



FEM Package

ANSYS is the name commonly used for ANSYS mechanical, general-purpose finite element analysis (FEA) computer aided engineering software tools developed by ANSYS Inc. ANSYS mechanical is a self contained analysis tool incorporating pre-processing such as creation of geometry and meshing, solver and post processing modules in a unified graphical user interface

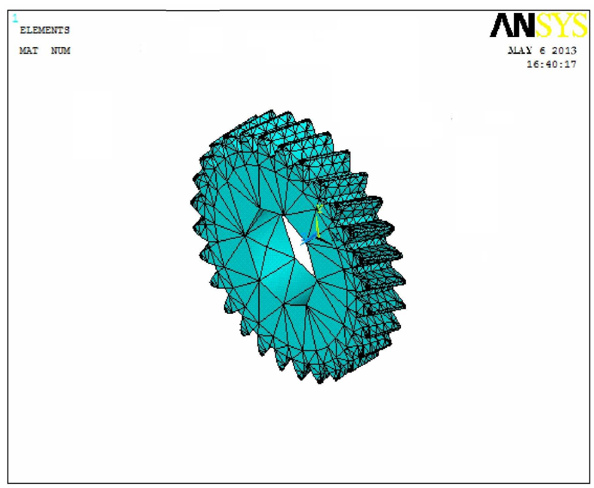
The following steps are used in the solution procedure using ANSYS

1. The geometry of the gear to be analyzed is imported from solid modeler Pro/Engineer in IGES format this is compatible with the ANSYS.
2. The element type and materials properties such as Young's modulus and Poisson's ratio are specified.
3. Meshing the three-dimensional gear model. Figure 4 shows the meshed 3D solid model of gear.
4. The boundary conditions and external loads are applied.
5. The solution is generated based on the previous input parameters.
6. Finally, the solution is viewed in a variety of displays.

FEM Bending Stress Analysis:

In this section, the teeth bending stress of helical gear is calculated using ANSYS. For this purpose the modeled gear in Pro/Engineer is exported to ANSYS as an IGES file and then an automatic mesh is generated. Figure 5.2shows the meshed three-dimensional model. Figure 5.3 demonstrate the Von Mises stress on the root of the tooth for 28 numbers of teeth helical gear. There are more detailed results for various numbers of teeth in Table 5.3 at section 5.4 which are compared with the result obtained from the Lewis formula.

Number of teeth (N)	Geometric factor (J) [22]	Maximum Bending Stress using AGMA Formula (Mpa)
20	0.5000	60
25	0.5300	57.04
28	0.5400	55.98
30	0.5500	54.97
37	0.5625	53.74



Three-dimensional FEM model with 28 teeth

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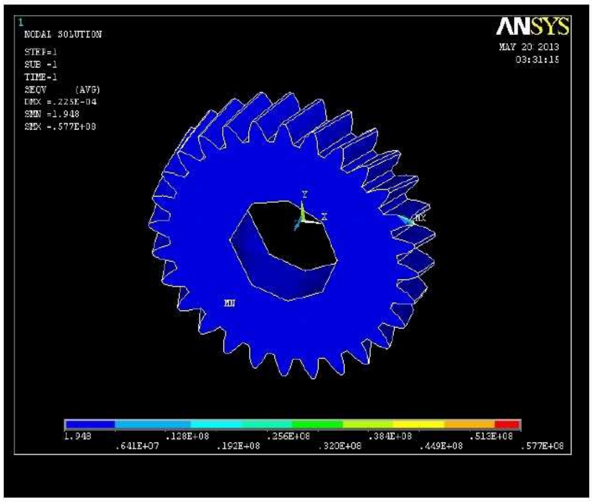


Von Mises stress of 28 number teeth modeled gear

Bending stress from ANSYS:-

Number of teeth (N)	Load (N/mm)	Maximum bending stress (ANSYS) (MPa)
20	287.75	61.44
25	287.75	59.63
28	287.75	57.70
30	287.75	57.07
37	287.75	56.86

Bending stress from AGMA formula:-

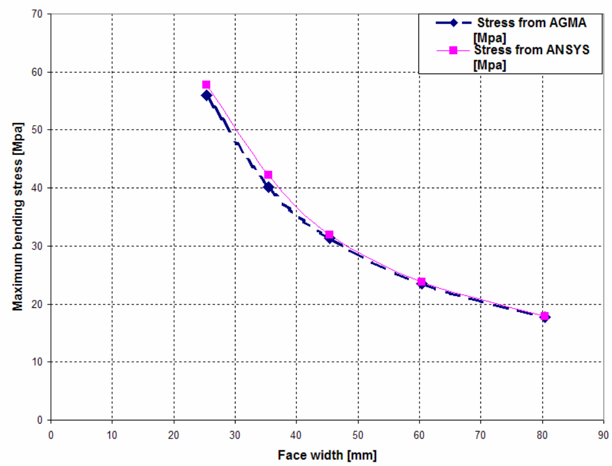
Number of teeth (N)	Geometric factor (J) [22]	Maximum Bending Stress using AGMA Formula (Mpa)
20	0.5000	60
25	0.5300	57.04
28	0.5400	55.98
30	0.5500	54.97
37	0.5625	53.74

Comparison of Results using AGMA Bending Stress Formula:

In this section, the bending stresses obtained from the analysis of the three-dimensional model using ANSYS is compared with the calculated values from the standard recommended by AGMA during the design of helical gears.

Number of Teeth (N)	σ_{AGMA} (Mpa)	σ_{ANSYS} (Mpa)	Differences (%)
20	60	61.44	2.35%
25	57.04	59.63	4.34%
28	55.98	57.70	2.98%
30	54.97	57.07	3.68%
37	53.74	56.86	5.49%

Effect of Face Width:



Conclusion

The strength of the gear tooth is a crucial parameter to prevent failure. In this study, it is shown that the effective method to estimate the root bending stresses using three dimensional model of the gear and to verify the accuracy of this method the results with different number of teeth are compared with the standard formula.

Based on the result from the contact stress analysis the hardness of the gear tooth profile can be improved to resist pitting failure: a phenomena in which a small particle are removed from the surface of the tooth that is because of the high contact stresses that are present between mating teeth.

As it is expected, in this work the maximum bending stress decreases with increasing face width and it will be higher on gear of lower face width with higher helix angle. As a result, based on this finding if the material strength value is criterion then a gear with any desired helix angle with relatively larger face width is preferred.

Recommendation and Future Work

This paper can be helpful for researchers, instructors and postgraduate students who want to work more on gears. It may give enlightenment about the characteristics of involute helical gears and evoke pervious works of various bodies that are involved in gears research and production. Furthermore this study contribute to a better gear design, assist technological institutions and all those who are interested in invloute helical gears. More work can be done to improve this study and to obtain better output. Generally, the following areas are worthy for further research in the light of this thesis.

- Further three dimensional numerical method of investigation and study can be conducted on the analysis of bending and contact stresses for all types of gears such as spur, bevel and other tooth forms.
- Further numerical method of investigation and study can be conducted on the whole gearbox with all elements in the system including gear casing and bearing.
- Further numerical method of investigation and study can be conducted on gears in mesh under dynamic condition with and without cracked teeth, surface pitting or wear.
- The bending and contact stress analysis of gears made of composite materials using three-dimensional finite element analyses can be recommended as future work.
- The contact stress can be reanalyzed for a better result by simulating the real contact region between the two mating gears instead of using the equivalent cylinders by improving the solution in a high capacity computer.

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