Design, Modeling and Analysis of Helical Gear According Bending Strength Using AGMA and ANSYS

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***Abstract* —there are two kinds of stresses in gear teeth, root bending stresses and tooth contact stresses. These two stresses results in the failure of gear teeth, root bending stress results in fatigue fracture and contact stresses results in pitting failure at the contact surface. So both these stresses are to be considered when designing gears. Usually heavily loaded gears are made of ferrous materials that have infinite life for bending loads. But it is impossible to design gears with infinite life against surface failure. In this paper one of the principal failure modes are studied based on the calculation of bending stress. Helical gears are widely used in industry where the power transmission is required at heavy loads with smoother and noiseless operation. To estimate the bending stress, three-dimensional solid models for different face width 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. In this paper a helical gear was modeled on Pro engineer wildfire 4.0 and stress analysis part is done on ANSYS 11.0. The results are then compared with both AGMA and FEM procedures.**

***Keywords*— Design, Modeling, Helical Gear, Bending Stress, AGMA, FEA**

I. Introduction

Power transmission has always been of high importance. The efficiency of any machine depends on the amount of power loss in the process. One of the best methods of transmitting power between the shafts is gears. Gears are mostly used to transmit torque and angular velocity. There are also a wide variety of gear types to choose from.

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]. The finite element method is proficient to supply this information but the time required to generate proper model is a large amount. Therefore to reduce the modeling time a pre-processor method that builds up the geometry required for finite element analysis may be used, such as Pro/Engineer. Pro/Engineer can generate three dimensional models of gears. In Pro/Engineer the generated model geometry is saved as a file and then transferred to ANSYS 11.0 for analysis.

The first systematic studies in gear dynamics started in the 1920s by A.A Ross and E.Buckingham [2]. The basic concern in their studies was the prediction of tooth dynamic loads for designing gears at higher speeds. This research attempts to review literatures, which are relevance to analysis gear of stresses.

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Vljayaragan and Ganesan [3] 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. The validity of their results of the FEM was tested by the root stress for C-45 steel material gear and comparing the result with obtained from conventional gear design equation. The paper presented also the evaluation of the performance of composite helical gears by companion of with that of the 6 conventional carbon steel gear. It is observed form the result that composite materials can be used safely for power transmission helical gears but the face width has to be suitably increased.

Saxena [4] analyzed the stress distribution in spur gear teeth using FEM program. He just studied a single teeth rather than whole spur gear. Spur gear profile was created in ANSYS. In his study he analyzed geometry factor for different type of gear profiles.

In 1992, Rao and Muthuveerappan [5] 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. A computer program has been developed for the stress analysis of the gear. Root stresses are evaluated for deferent positions of the contact line when it moves from the root to the tip. To check the validity of the developed program, the changes in the trend of the maximum root stress values at various places of the tooth along the face width were compared with the experimental results. A parametric study was made by varying the face width and the helix angle to study their effect on the root stresses of helical gears. Based on their investigation the effect of helix angle and face width on the root stresses of helical gears was clarified for different positions of the contact line.

II. DESIGNING OF GEAR

A. General Design Considerations

The proper design of gears for power transmission for a particular application is a function of (a) the expected transmitted power, (b) the driving gear's speed, (c) the driven gear's speed or speed ratio and (d) the centre distance (Khurmi and Gupta 2009). In this paper we designed the helical according bending strength condition and the tooth bending stress equation for helical gear teeth is given as

$$\sigma_b = \frac{F_t}{bmJ} K_V K_O \ (0.93K_m) \qquad \dots (1)$$

Introduction of constant 0.93 with the mounting factor reflects slightly lower sensitivity of helical gears to mounting conditions. All the calculations are carried out on the basis of eq. (1) recommended by AGMA

From which the pitch circle diameter of pinion gear was derived to be given as

$$D \geq \frac{2T}{bmJ\,[\sigma_b]} K_V K_O \ (0.93K_m)$$

Where,

Force transmitted (F_t) = 1591.53 N

Face width (b) = 100 mm

Normal module (m) = 10 mm

Geometry factor (J) = 0.56

Velocity Factor (Kv) = 1.34

Overload factor (K_O) = 1.25

Load distribution factor (Km) = 1.3

B. Tangential force calculation:

In order to design the gear according to bending strength condition the following parameters were assumed:

Power (P) = 30 kW

Speed = 1200 R.P.M

$$Torque\ (T_P) = \frac{9549.3 \times P(kW)}{speed\ (RPM)} = 238.73\ N.\text{m}$$

$$\text{Tangential Force (Ft)}\ \frac{2000 \times T_P}{Pitch\ diameter} = 1591.53N$$

C. Bending Stress Calculation (σ_b AGMA):

After the tangential force was calculated the AGMA bending stress calculation is carry out using equation (1) for five (5) different faces wide (b = 100mm, 95mm, 90mm, 85mm, 80mm) as follows:

$$\sigma_{bAGMA1} = \frac{1591.53}{100 \times 10 \times 0.56} \times 1.34 \times 1.25(0.93 \times 1.3) = 5.7553\ MPa$$

$$\sigma_{bAGMA2} = \frac{1591.53}{95 \times 10 \times 0.56} \times 1.34 \times 1.25(0.93 \times 1.3) = 6.0582\ MPa$$

$$\sigma_{bAGMA3} = \frac{1591.53}{90 \times 10 \times 0.56} \times 1.34 \times 1.25(0.93 \times 1.3) = 6.3948\ MPa$$

$$\sigma_{bAGMA2} = \frac{1591.53}{85 \times 10 \times 0.56} \times 1.34 \times 1.25(0.93 \times 1.3) = 6.7709\ MPa$$

$$\sigma_{bAGMA2} = \frac{1591.53}{80 \times 10 \times 0.56} \times 1.34 \times 1.25(0.93 \times 1.3) = 7.1941\ MPa$$

III. MODELING OF GEAR

The most complicated part in any gear modeling is the involute profile of its teeth. There are number of ways of creating involute profile of a helical gear. In this paper the helical gear model was designed in Pro Engineer design modeler. Pro/E is a suite of programs, which are basically used in designing and manufacturing range of products. This paper basically deals with the solid modeling feature of Pro/E. In the case of these analyses five different gear were modeled in Pro/ENGINEER Wildfire [6], by varying the face width. The parameters and the materials properties used for gear modeling are tabulated below:

TABLE I Gear parameter

S/N:	Variable Name	Description	Value	Units
1	Z	NO. of Teeth	30	
2	M	Module	10	mm
3	D	Pitch diameter	300	mm
4	PHI	Pressure angle	20	degree
5	β	Helix angle	15	degree
6	F	Face width	100	mm

7	A	Addendum	10	mm
8	B	Dedendum	1.25*A	mm
9	E	Modulus of Elasticity	200	GPa
10	V	Poisson’s ratio	0.3	
11	P	Power	30	kW
12	N	Speed	1200	Rev/min

The word ‘Relation’ and ‘Equation’ itself gives the idea about relating the feature with the help of equations. The procedure used to model the gear of 30 number of teeth with the combination of the all above mentioned parameters in the Pro/ENGINEER Wildfire, are carry out using Tools parameter/relation menu. First step is to define the basic parameters on which the model has dependencies. This can be done by going to Tools / Parameters menu, and inserting the basic gear parameters and then go to Tools/relation to relate these parameters using equations. Relations are used to express dependencies between the dimensions of a feature. Figure 1 and 2 showing the Tools parameter/Relation menu and 3D modeled of a helical gear from Pro/Engineer screen respectively.

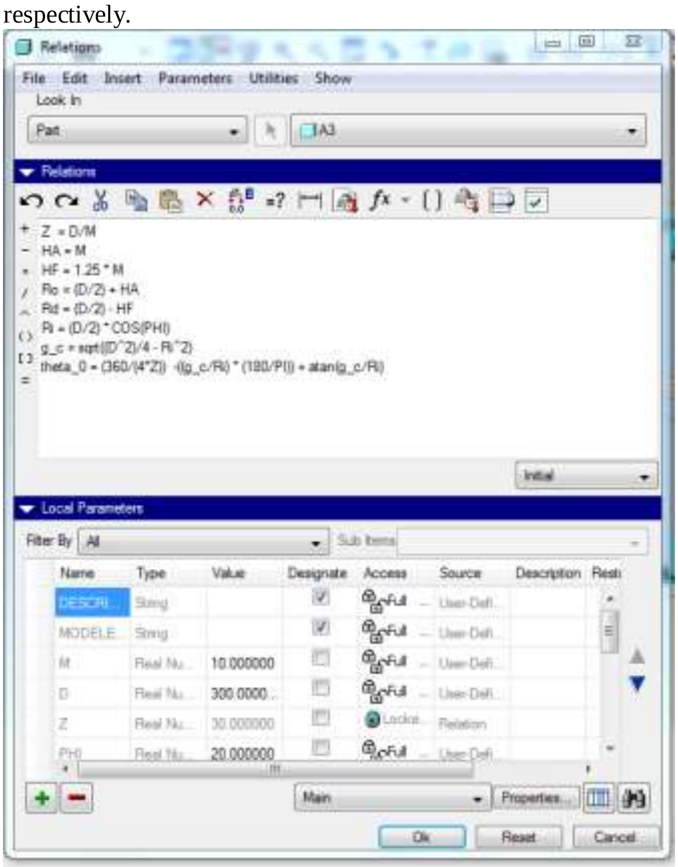

Fig. 1 Tools parameter/Relation menu

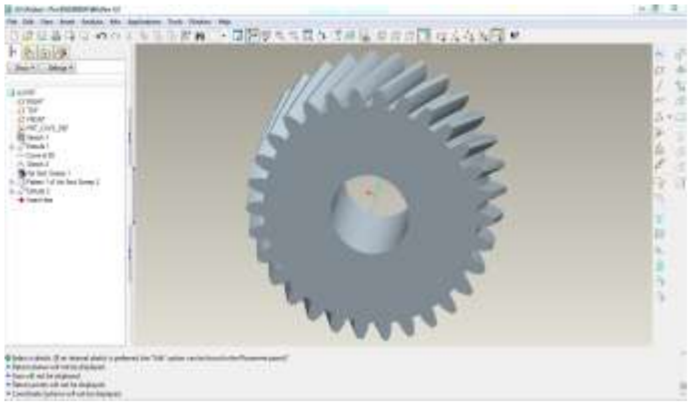

Fig. 2 3D Helical Gear Modeled

IV. VON MISES (BENDING) STRESSES

A. *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 paper, the three-dimensional eight nodded 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.

B. *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. ANSYS is a general-purpose finite element-modeling package for numerically solving a wide variety of mechanical and other engineering problems. These problems include linear structural and contact analysis that is non-linear. Among the various FEM packages, in this work ANSYS is used to perform the analysis [7]. 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 3 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.

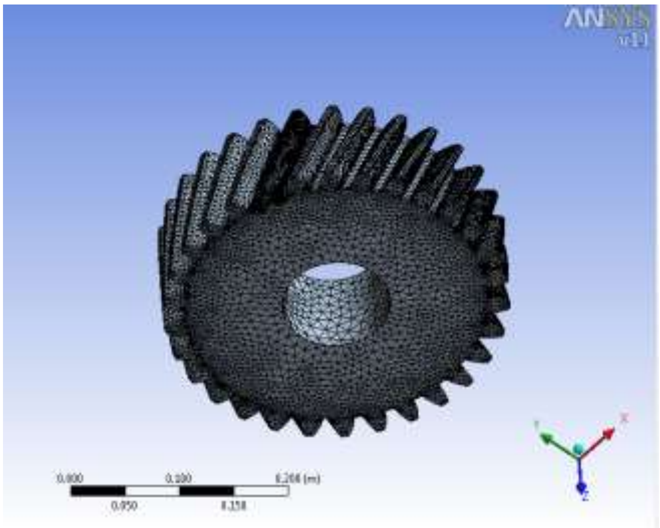

Fig. 3 Meshed 3-D Model of Helical gear

Therefore, by varying the face Width and keeping the other parameters constant various models of the helical gear are analyze and two of the models created by varying face width are shown in Figure 4 and Figure 5 respectively.

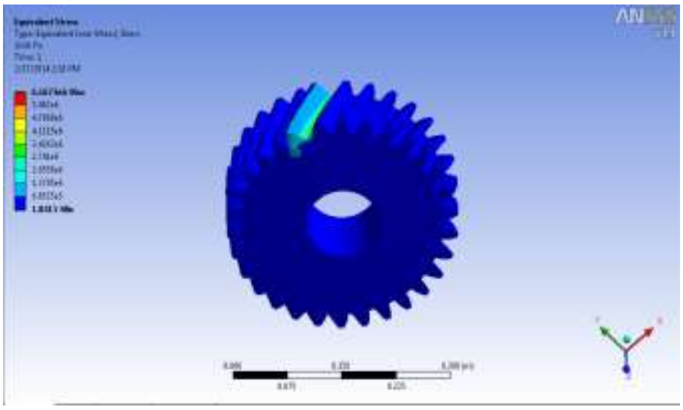

Fig. 4 gear having 30 teeth (face width =95 mm)

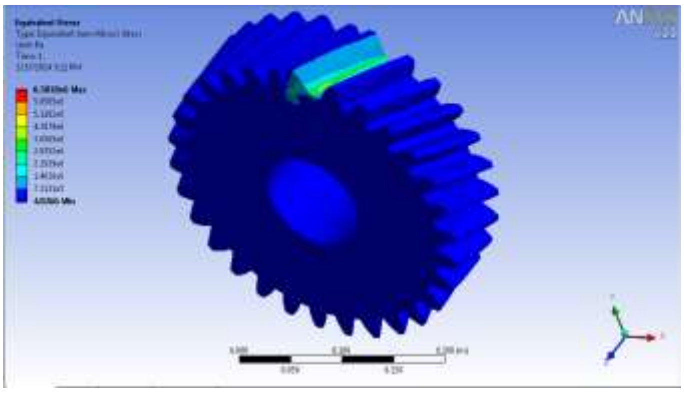

Fig. 4 gear having 30 teeth (face width =85 mm)

V. RESULT AND DISCUSSION

Face width and helix angle are important geometrical parameters in determining the state of stresses during the design of gears. Thus, the objective of this work is to conduct a parametric study by varying the face width to study their effect on the bending stress of helical gear. In order to determine the stresses variation with the face width five different models of helical were created by keeping other parameters (i.e. module, pitch circle diameter, number of teeth, helix angle etc) constant. Table II below shows the results of bending stress with the variation in the face width of the helical gear tooth.

TABLE II Bending Stress (MPa)

S/N	Face width [mm]	AGMA [Mpa]	ANSYS [Mpa]	Differences [%]
1	80	7.1941	7.0256	2.34
2	85	6.7709	6.5818	2.80
3	90	6.3948	6.4873	1.44
4	95	6.0582	6.1673	1.80
5	100	5.7553	5.4856	4.70

The table above clearly shows that as the face width is increasing there is a corresponding decrease in the value of the tooth bending stresses of a helical gear calculated from the AGMA as well as that obtained from ANSYS analysis. Therefore, from the results obtained we can say that for any constant load and speed, the gear with higher face width is suitable. Fig. 5 shows the Graph of Bending Stress [MPa] against Face width [mm].

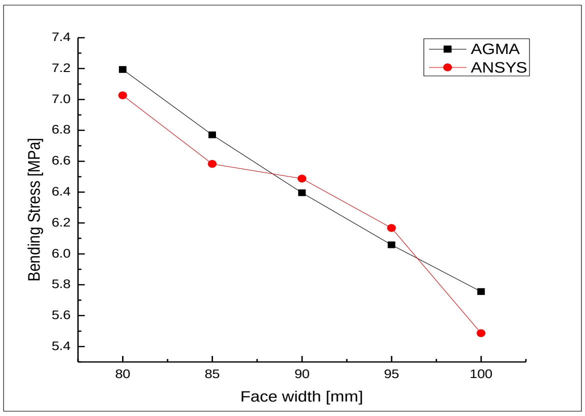

Fig. 5 Graph of Bending Stress [MPa] against Face width [mm]

VI. CONCLUTION

The results obtained from ANSYS when compare with the AGMA procedure, it shows that there is a little variation with a higher difference in percentage of 4.70%. From the results we can conclude that ANSYS can also be used for predicting the values of bending stress at any required face width which is much easier to use to solve complex design problems like gears.

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