Analysis of Bending Stress of Spur Gear By FEM

[1] Dr. P K Sharma, [2] Chandra Prakash
[1] *Head of Dept.* [2]*M. Tech Student*
Mechanical Engineering Department NIIST BHOPAL (M.P) India

Abstract - One of the very common types of gears – spur gears – is considered in this paper to analyze and hence predict the stresses in them using the most versatile numerical techniques in practice, the Finite Element Method (FEM). Stresses arise in gears due to forces from an external structural component which gives rise to bending stresses in general CATIA software has been used to model the gear domain having an involute profile, subjected to certain key features, like number of teeth, module and pressure angle and the model is imported to ANSYS software to mesh and analyze it by the FEM.

Keywords: Spur Gear, Involute, Gear Failure, Bending Stress, Module, Pressure Angle, FEA, AGMA, CATIA, ANSYS.

I. INTRODUCTION

The efficiency of any machine depends on the amount of power lost in the process. One of the best methods of transmitting power between the shafts is through gears. Gears are mostly used to transmit torque and angular velocity. Gears generally fail when the working stress exceeds the maximum permissible stress. Numbers of studies have been conducted by various authors to analyze stresses in gears[1, 2, 3, 4]. Gears have been analyzed for different points of contact on the tooth profile and the corresponding point of contact on the pinion. There are a wide variety of gear types to choose from. This paper considers spur gear designed to operate on parallel shafts and having teeth parallel to the shaft axis. Gears are standardized by AGMA (American Gear Manufacturers Association) depending on size and tooth shape[5]. In this paper AGMA methods and standards are used for validation of results.

Reduction in noise while transferring power is important in today's rapidly growing field of automobile industry. One of the effective ways to achieve gear noise reduction is to reduce the vibration associated with them. Designing highly loaded spur gears for power transmission systems that are both strong and quiet requires analysis methods that can easily be implemented and also provide information on bending stresses. The finite element method is capable of providing this information, but the time needed to create such geometry is large[6, 7, 8].In order to reduce the modeling time, a pre-processor method that creates the geometry needed for a finite element analysis is used. Modeling software like Pro Engineer, Solid Works, CATIA and many more are the best option available to create complex geometry for analysis. In this paper, CATIA is used to create the Gear geometry and then it is imported in ANSYS Workbench 13.0 for analysis. Gear analyses in the past were performed using analytical methods, which required a number of assumptions and simplifications. In general, gear analyses are multidisciplinary, including calculations related to the tooth stresses and the failures. In this paper, bending stress analyses are performed, with the main aim of designing spur gears to resist bending failure. Nowadays computers are becoming more and more powerful, and that is the reason why people tend to use numerical approach to develop theoretical models to predict the effects. Numerical methods, in general provide approximate solutions and the approximation gives way to near exactness as the number of sub-divisions or finite elements of the physical domain tend to infinity. But, a trade-off between accuracy of solution and computation time is always an important consideration in such methods. In this paper, first the solid model of the spur gear is made with relations and equations modeling option in CATIA. After the modeling of spur gear the assembly is created of two spur gears in contact. The contact is defined at the pitch circle radius with the appropriate centre distance between the two gears. Then the whole assembly is imported in ANSYS Workbench 13.0 for bending stress analysis. The results of ANSYS 13.0 are then compared with the AGMA standards for the specified gear set in contact. The purpose of this project is to develop a general model to study bending stress of spur gears in contact.

II. PAPER WORK DETAILS

A) Objectives of Paper

There are a number of investigations devoted to gear research and analysis. But still there remains a general numerical approach capable of predicting the effects of variations in gear geometry, bending stresses. The objectives of this paper are to use a numerical approach to develop theoretical models of the behaviour of spur gears in mesh, to help to predict the effect of gear tooth stresses. The major work is summarized as follows.

- Applying the relation equation in CATIA to develop accurate three dimensional spur models. It is easy to change the parameters of gear to arrive at different model to analysis.
- Applying Formula of Lewis bending equation and finite element meshing for spur gear.
- Performing parametric studies of three-dimensional finite element models of spur gear to investigate the root bending stress distribution over the assumed operating speed.
- Application of FEM in stress analysis of spur gear & convergence study of a few finite elements.
- Validation of the results from the finite element analysis, with the results obtained according to AGMA standards.

There are many types of gear failures which can be classified into two general groups. One is failure of the root of the teeth because of inadequate bending strength. The other is created on the surfaces of the gears. There are two theoretical formulae, which deal with these two failure mechanisms. One is the Hertzian equation, which can be used to calculate the contact stresses. The other is Lewis formula, which can be used to calculate the bending stresses[9]. The surface pitting and scoring are the examples of failures, which resulted in the fatigue failure of tooth surface. Pitting and scoring is a phenomenon in which small particles are removed from the surface of the tooth due to high contact stresses that are present between mating teeth. Pitting is actually the fatigue failure of the tooth surface. Hardness is the primary property of the gear tooth that provides resistance to pitting. In other words, pitting is a surface fatigue failure due to many repetitions of high contact stress, which occurs on gear tooth surfaces when a pair of teeth is transmitting power.

B) Modelling Set up

The first step in this paper is to model a spur gear assembly. The most complicated part in spur gear is the involute profile of its teeth. There are a number of ways of creating involute profile of a spur gear. In this paper, the spur gear model was designed in CATIA design workbench. CATIA is a suite of programs, which are basically used in designing and manufacturing a range of products.

By defining the parameters and relation in CATIA final gear model will look likeFig.2 and by changing the parameters, angular degree (a), module (m), and number of teeth (z) we will get different gears.

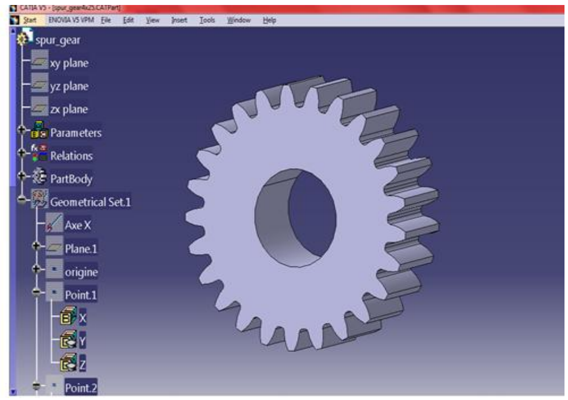

Fig.2 Solid model of gear in CATIA

To make the analysis precise and less time consuming, gear with only one tooth is considered. It is easy to remove other teeth by pocketing. Pocketing is a tool used to remove the selected profile in a solid body .The two gears are then assembled by defining the tangential contact between the teeth and by constraining them to calculated center distance. The image below from CATIA shows two gears meshed at their pitch circle radius.

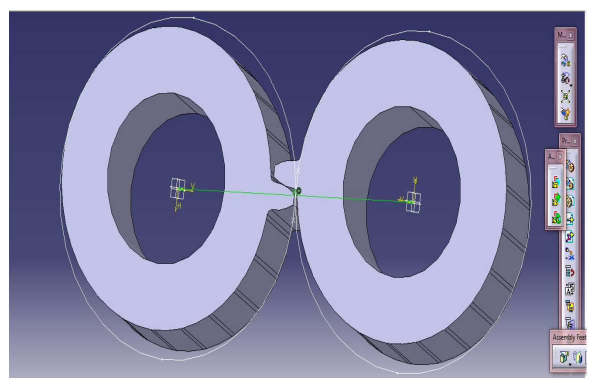

Fig.3Assembly of Spur Gear In Mesh

For bending stress analysis the spur gear pair with the properties given in table 1 was chosen to model.

Table 1: Spur Gear parameters		
1	Modulus of Elasticity	200 Gpa
2	Poission ratio	0.3
3	Type of Gear	Standard Involute, Full depth
4	Module	4 mm
5	Pressure Angle	20°
6	Face width(F)	43 mm
7	No of teeth(N)	25
8	Pitch Diameter	100 mm
9	Transmitted load(W)	3000 N
10	Revolution Per Minute(RPM)	3000
11	Torque	150 Nm
12	Material	SCM420

Table 1 Spur Gear Parameters

To minimize computation time, meshed gear with one tooth is imported to ANSYS Workbench 13 for analysis. Fig 4 Shows the Geometry of gear for analysis

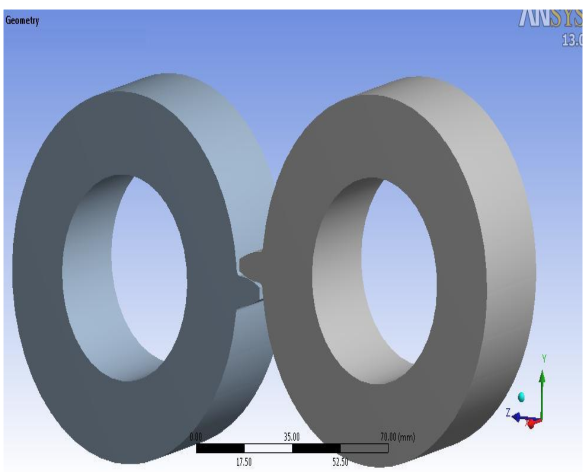

Fig. 4 Geometry of gear for analysis

III. RESULTS

Using ANSYS, three dimensional root bending stresses are obtained, which are then compared with the AGMA theoretical stress. Here analyses of gears with different numbers of teeth are carried out keeping the module, pressure angle and face width fixed.

The values of the same adopted for the spur gear model are: 4mm, 20^0 and 43mm respectively. The transmitted load is 3000 N.

The values for the factors k_v , k_o and k_m are taken from machine design book Norton (2008).

For uniform power transmission, uniform driving torque and face width less than 50mm the values of k_v , k_o and k_m are 1.2, 1.25 and 1.3, respectively.

AGMA bending stress is given as:

For the number of teeth (Z) = 22

$$\sigma_b = \frac{F_t}{bmJ} k_v k_o k_m = \frac{3000}{43 \times 4 \times 0.35185} \times 1.2 \times 1.25 \times 1.3 = 97.47\ MPa$$

For number of teeth (Z) = 25

$$\sigma_b = \frac{F_t}{bmJ} k_v k_o k_m = \frac{3000}{43 \times 4 \times 0.3687} \times 1.2 \times 1.25 \times 1.3 = 92.24\ MPa$$

For number of teeth (Z) = 28

$$\sigma_b = \frac{F_t}{bmJ} k_v k_o k_m = \frac{3000}{43 \times 4 \times .3858} \times 1.22 \times 1.25 \times 1.3 = 89.62 MPa$$

For number of teeth (Z) = 30

$$\sigma_b = \frac{F_t}{bmJ} k_v k_o k_m = \frac{3000}{43 \times 4 \times 0.3904} \times 1.22 \times 1.25 \times 1.3 = 87.12 MPa$$

For number of teeth (Z) =34

$$\sigma_b = \frac{F_t}{bmJ} k_v k_o k_m = \frac{3000}{43 \times 4 \times 0.405026} \times 1.22 \times 1.25 \times 1.3 = 85.37 MPa$$

The Fig.5 shows the stress distribution in 3-D models and the Table 2 list the comparison of results for different3-D models and the corresponding AGMA stress values.

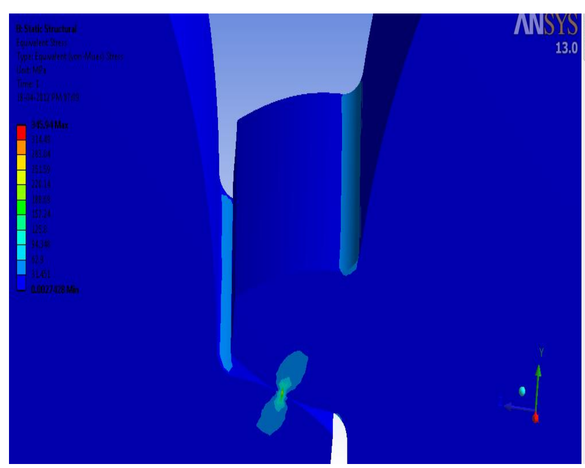

Fig.5 D Von-Mises Stress for Gear with 25 Teeth

Table 2 : Maximum Von-Mises(Bending) Stresses for Spur gear Models

No of teeth(N)	AGMA Stresses(MPA)	3D Stresses (ANSYS) (MPA)
22	97.47	96.52
25	92.24	94.34
28	89.62	91.32
30	87.12	85.84
34	85.37	82.33

IV. CONCLUSION

Spur gears in contact are analyzed for bending stress in this paper using the most versatile numerical technique, the FEM. The loading on the gear is a torque and the stresses are calculated using the non-linear elasticity approach in the FEM. Isotropic material properties are assumed for the material of the gear. CATIA software has been employed for modeling the gear assembly and meshing is materialized in the workbench of ANSYS software. It was observed that the stresses generated on spur gear teeth changes with the number of teeth. A comparison of the results obtained from the FEM with those using the AGMA (maximum bending stresses) reveals that that the maximum stresses predicted by the FEM are slightly higher than those predicted by the AGMA. But this difference is of very small magnitude in comparison with the actual stress values and can be attributed to the difference in the theories involved. It may also be stated that since the results predicted by the FEM differ only slightly and most of them being an upper bound solution and also the stresses need to be evaluated in the whole domain of the gear, the FEM can be used for the analysis of spur gears without much loss of accuracy. Hence the results from this FE model of spur gear can be used for further research such as spur gear fatigue and design.

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