Comparison of Bending Stresses in Involute and Cycloidal Profile Spur Gear Tooth

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Abstract - *In this paper, the analysis of involute and cycloidal tooth spur gear design has been done to investigate the bending stresses induced in the gear tooth for different modules by finite element analysis. The mathematical models have been generated based on the theory of gearing. Models are made in Creo Parametric software tool. The bending stresses induced in the gear tooth obtained from FEA corresponding to different modules for both involute and cycloidal profile spur gear are compared with the values obtained by Lewis equation. It is observed that the FEA results are having a slight variation with Lewis equation. It is found that the bending stress reduces with the increase in module and the bending stress values for involute profile spur gear is less than the cycloidal profile for the same module and involute spur gear teeth is stronger than cycloidal spur gear teeth.*

***Key Words*: Lewis Equation, Spur Gear**

1. INTRODUCTION

Gears are used for a variety of applications. They are the most efficient way to transmit power. For high speed machines, such as in a motor vehicle transmission, they are the optimum medium for low energy loss, high accuracy and reliability. A set of teeth is generally subjected to two types of cyclic stresses:

i) Bending stress including bending fatigue.
ii) Contact stress causing contact fatigue.

In this paper, the problems arriving on gear tooth due to bending failure in involute and cycloidal profile has been investigated. Gear failure occurs at the mating portions of a gear pair which are usually subjected to cyclic stress which causes tooth-bending fatigue, tooth-bending impact, and tooth wear. When two gears meshing with each other to transmit the load, the teeth of every gear is under bending stress. The bending stress is maximum at the root of the tooth. Because of the periodical impact of load, fatigue cracks might occur close to the tooth base that produces failure of the tooth.

2. LITERATURE REVIEW

Liang et al [1] evaluated the meshing characteristics of tooth surfaces according to the analysis of motion simulation, mechanics property and sliding coefficient. The transmission efficiency experiment is based on the developed gear prototype, and a comparison with an involute gear drive is presented. The further study on dynamics analysis and key manufacturing technology will be conducted, and this new type of gear drive is expected to have excellent transmission performance.

Malek [2] presented a brief review of design and modeling and analyzed high speed helical gear using AGMA and ANSYS with various face width and helix angle and found their effect due to bending and contact stress and its value compared with ANSYS and AGMA.

Venkatesh & Murthy [3] calculated the bending and contact stresses of involute helical gear. Pro-e solid modeling software is used to generate the 3-D solid model of helical gear. Bending stresses are calculated by using modified Lewis beam strength equation and ANSYS software package. Contact stresses are calculated by using AGMA contact stress equation and ANSYS software package. Finally, these two methods bending and contact stress results are compared with each other.

Patil et al [4] evaluated the contact stresses among the helical gear pairs, under static conditions, by using a 3D finite element method. The helical gear pairs on which the analysis was carried are 0, 5, 15, 25-degree helical gear sets. The FE results have been further compared with the analytical calculations. The analytical calculations are based upon Hertz and AGMA equations, which are modified to include helix angle. The contact stress results have shown a decreasing trend, with increase in helix angle.

Vishwakarma et al [5] investigated the stresses induced in tooth flank, tooth fillet during meshing of gears. The involute profile of helical gear has been modeled and the simulation is carried out for the bending and contact stresses and the same have been estimated. For the estimation of bending and contact stresses, 3D models are generated by modeling software CATIA V5 and simulation is done by finite element software package ANSYS 14.0. Analytical method of calculating gear bending stresses uses Lewis and AGMA bending equation. For contact stresses Hertz and AGMA contact equation are used. Study is conducted by varying the face width to find its effect on the bending stress of helical gear. It is therefore observed that the maximum bending stress decreases with increasing face width. The stresses found from ANSYS results are compared with those from theoretical and AGMA values.

Hong et al [6] generated a new conjugated tooth profile by applying double-enveloping gear theory in cycloid drives. Based on coordinate transformation and gear geometry theory investigated by theoretical analysis and numerical new conjugated tooth profile is represented by comparison of induced normal curvature with conventional cycloid drives.

Liang et al [7] studied the basic principle characterized by the advantages of involute and circular-arc gear. Based on the theory of conjugates curves, generation and mathematical model of this new transmission are presented. Finally, the three-dimensional solid model of a gear pair is developed to demonstrate the properties of this new transmission.

Tiwari and Joshi [8] evaluated the contact stress and bending stress of mating involute spur gear teeth. FEM software has been used to perform meshing simulation. It was observed that the theoretical results obtained by Lewis formula and Hertz equation and results found by AGMA/ANSI equations are comparable with Finite Element Analysis of spur gear.

Venkatesh et al [9] carried out structural analysis on a high speed helical gear used in marine engines. The dimensions of the model have been arrived at by theoretical methods. The stresses generated and the deflections of the tooth have been analyzed for different materials. Finally, the results obtained by theoretical analysis and Finite Element Analysis are compared to check the correctness. A conclusion has been arrived on the material which is best suited for the marine engines based on the results. Basically, the project involves the design, modeling and manufacturing of helical gears in marine applications. It is proposed to focus on reduction of weight and producing high accuracy gears.

3. GEAR SPECIFICATIONS

No. of teeth on Gear	=	50
No. of teeth on Pinion	=	18
Module of the gears	=	2.5 mm
Face width	=	30 mm
Pinion speed	=	1425 rpm
Young's modulus	=	2.1×10^5 MPa
Poisson's ratio	=	0.3

4. MATERIAL SELECTION

In this investigation, the grade 1 steel has been considered as material for both gear and pinion due to its non-shrinking charecteristic, general purpose tool steel with good abrasion resistance, toughness, and machinability. It is extremely stable with minimal deformation after hardening and tempering. Maximum attainable Rockwell hardness is C57-C62. Melting point is 2800° F.

5. RESULTS AND DISCUSSIONS

A finite element analysis has been carried out to investigate the bending stresses induced in both involute and cycloidal spur gear tooth. The models have been generated in Creo parametric software and analyzed in ANSYS software tool. The results for module of 2 mm for both pinion and gear of involute and cycloidal profile has been shown below from figure A to D which was performed in ANSYS structural analysis with same boundary domain conditions.

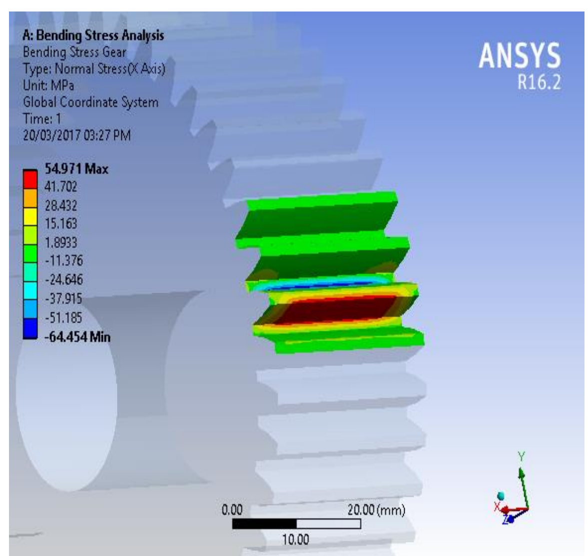

Fig-A: Bending stress in involute gear

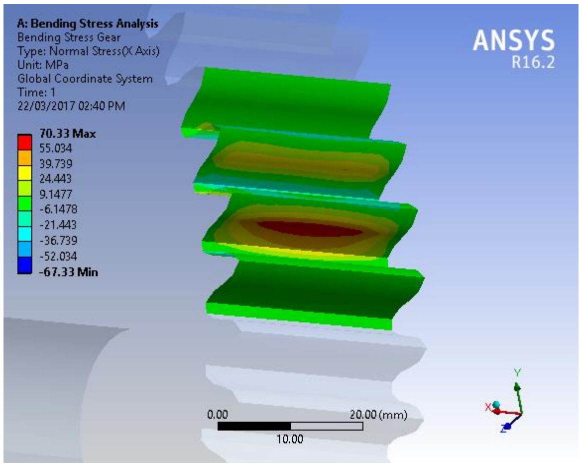

Fig-B: Bending stress in cycloidal gear

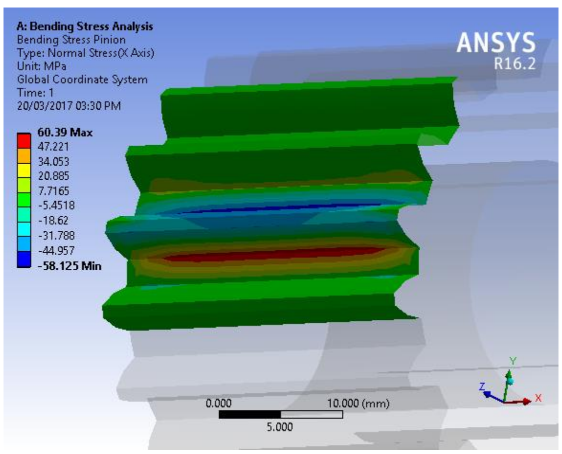

Fig-C: Bending stress in involute pinion

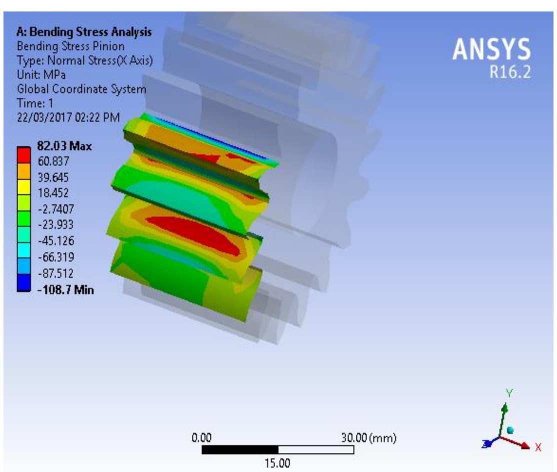

Fig-D: Bending stress in cycloidal pinion

The above results have been tabulated and a comparison is made between involute and cycloidal profile spur gear and pinion teeth which are shown below

Table-1: Involute gear bending stress results obtained from literature [8] and FEA

Module, mm	Bending Stress, MPa			% Error
	Lewis Formula	Literature	FEA	
2.5 Gear	63	42.94	43.11	0.4%
2.5 Pinion	46.36	55.61	56.39	1.5%

Table 1 indicates that the percentage difference between literature [8] and present work for 2.5 mm module is 0.4% for gear and 1.5% for pinion which are under consideration for analysis.

Table-2: Comparison of bending stress in involute and cycloid pinion teeth

Module, mm	Bending Stress, MPa		
	Involute Pinion	Cycloid Pinion	% Differenc e
2	60.39	82.03	26.38
2.5	55.61	73.12	23.95
3	47.564	66.112	28.06
4	41.1	61.87	33.57
5	37.122	54.64	32.06

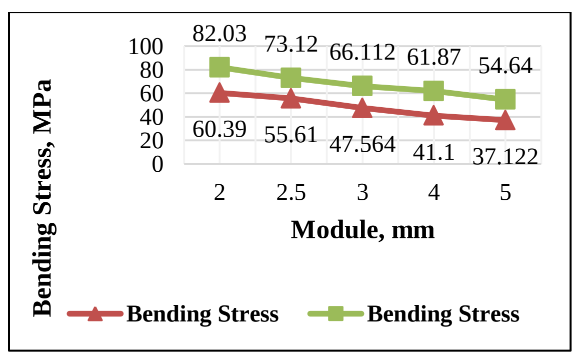

Chart-1: Variation of bending stress with different modules for involute and cycloidal pinion teeth

The variation of bending stress induced in the pinion with different modules is shown in chart 1. It is observed that the bending stress in involute pinion teeth is lower than the cycloidal pinion teeth for the same module. With the increase in module from 2mm to 5mm, the bending stress decreases for both involute and cycloidal profile spur gear.

Table-3: Comparison of Contact stress in involute and cycloid gear teeth

Module, mm	Bending Stress, MPa		
	Involute Gear	Cycloid Gear	% Difference
2	54.971	70.33	21.84
2.5	42.94	64.61	33.54
3	35.626	56.625	37.08
4	30.531	49.9	38.82
5	24.113	42.37	43.09

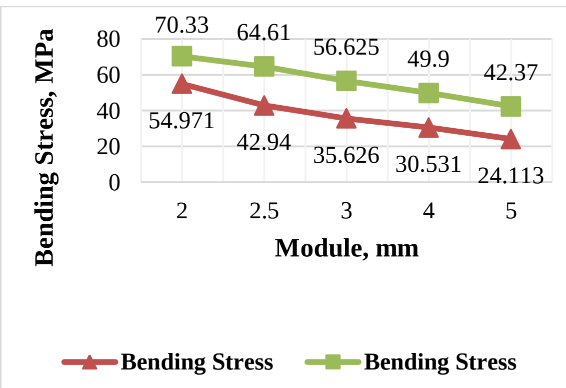

Chart-2: Variation of bending stress with different modules for involute and cycloidal gear teeth

The variation of bending stress induced in the pinion with different modules is shown in chart 2. It is observed that the bending stress in involute pinion teeth is lower than the cycloidal pinion teeth for the same module. With the increase in module from 2mm to 5mm, the bending stress decreases for both involute and cycloidal profile spur gear.

6. CONCLUSION

Results presented in this paper from finite element analysis are compared from the literature review and Lewis equation and it is found that a slight variation is obtained which is under consideration. Further comparison is made between involute and cycloidal pinion and gear teeth and it is concluded that for any value of module, the bending stress for involute spur gear teeth is less than cycloidal spur gear teeth, also the bending stress values for any profile spur gear decreases with the increasing module.

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