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Investigating the Effect of Material Change on Strength of Helical Gear

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Abstract: *In this paper, the stress analysis of helical gear pair is carried by using 20MnCr5 (Alloy Steel) and Grey Cast Iron. The effect of change in material for same helical gear pair is studied. The analytical stress values are evaluated by using AGMA equation. The result is compared with the ANSYS Workbench 16.1 version. The objective of the study is to suggest a comparable material to replace Alloy Steel.*
Keywords: *Gear Strength, Alloy Steel, Grey Cast Iron, Stress Analysis.*

I. INTRODUCTION

The most significant developments in the gear are in the area of materials. Modern metallurgy has greatly increased the useful life of industrial and automotive gearing to new levels of accuracy, reliability and quiet operation. The following [1] are the requirements that must be met in the design of gear drive; the gear teeth should have sufficient strength, so that they will not fail under static and dynamic loading during normal running conditions. The gear teeth should have clear characteristics so that their life is satisfactory, the use of space and material should be economical. Material selection can play an important role in the constant battle to reduce gear noise. Specifying tighter dimensional tolerances or redesigning the gear are the most common approaches design engineers take to minimize noise, but either approach can add cost to the finished part and strain the relationship between the machine shop and the end user. This paper represents a comparative analysis of materials with different damping abilities with respect to bending stress and contact stress. The literature related to the analysis of gears has been studied and reported herewith. The researcher [2] presented a paper on design, modeling and structural analysis of helical gear for Ceramic and Steel material by using ANSYS. The researchers observed that the bending and compressive stresses of ceramics are less than that of the steel. Also, further added that the weight reduction is a very important criterion for which aluminum material is preferred. The researcher [3] investigated the finite element model for monitoring the stresses induced of tooth flank, tooth fillet during meshing of gears. The researchers observed that the maximum bending stress decreases with increasing face width. The authors [4] carried out the contact stress analysis of helical gear by using AGMA and ANSYS. The researchers observed that during the contact of gear and pinion, the contact stress is decreased with the increase of face width. The researchers [5] presented a paper on design, simulation and analysis of helical gear. In this paper the simulation has conducted by varying the face width and helix angle and stress distribution pattern has been observed.

The researchers [6] carried out the work on comparison of bending stress and contact stress of helical gear as calculated by AGMA standards and FEA. In this paper, bending stress at the root of the helical gear tooth and surface contact stresses are computed by using theoretical method as well as FEA. The paper [7] presented on design and structural analysis of high speed helical gear using ANSYS. For estimating the bending stress modified Lewis beam strength method is used. Pro-e solid modeling software is used to generate the 3-D solid model of helical gear. ANSYS software package is used to analyze the bending stress. The researcher stated that if the material strength value is criterion then a gear with minimum number of teeth with any maximum helix angle of more face width is preferred. The authors [8] worked on the materials concluded that amongst the applied materials titanium alloy has shown less von misses stresses. And the 42CrMo4 steel is the best material for the fabrication of the designed helical gear and followed by chrome vanadium steel. The researcher [9] carried out the contact stress analysis of helical gear pairs of different materials such as Steel, Cast iron, Aluminum under static conditions, by using a 3D finite element method. The researchers selected helical gear pairs on which the analysis has been carried out were 10, 15, 20, 25 degree. The helical gear contact stress is evaluated using FEA. The researchers [10] studied the helical gear analysis using FEA software. The researchers stated that as the no of nodes go on increasing Von-mises equivalent stresses initially decreases & then gradually increases. The work [11] is done by the researchers on the stress analysis of mating teeth of spur gear to find maximum contact stress in the gear teeth. For the analysis, researchers have used steel and grey cast iron as the materials of spur gear. The researchers found that the results from both Hertz equation and Finite Element Analysis comparable. From the deformation pattern of steel and grey cast iron concluded that difference between the maximum values of steel and grey CI gear deformation is very less. From the literature review it is observed that the Gear parameters such as helix angle, face width and Material properties play a vital role in enhancing the gear strength. Material selection is the most important step while designing the gear.

II. BENDING STRESS AND CONTACT STRESS ANALYSIS

The parametric design modelling of helical gear and pinion in CATIA V5 is as shown in Fig.1.

Fig. 1 Helical Gear- Pinion Assembly

The theoretical Bending stress and Contact stress evaluation is done by using AGMA equation. The Helical gear pair specifications are mentioned in Table. 1.

Table: 1 Specifications of Helical gear pair

Parameters	Pinion	Gear
Number of teeth	12	59
Module (mm)	2.75	2.75
Pitch circle diameter (mm)	34.648	170.352
Helix angle (degrees)	17.74	17.74
Face width (mm)	47	35
Pressure angle (degrees)	20	20
Speed (r.p.m.)	1500	306

Bending Stress:

$$F_t = \frac{60\times10^6\times P}{2\times\pi\times N} \quad (1)$$

$$F_t = 4112.31 \text{ N}$$

$$\sigma_b = \frac{F_t}{b\times m\times J}\times k_v\times k_0\times 0.93\times k_m \quad (2)$$

The bending stress is 87.79 MPa

Contact stress:

$$\sigma_c = Z_E\,\frac{F_t\times k_v\times k_0\times k_s\times k_h\times Z_r}{d_{w1}\times Z_i} \quad (3)$$

The Contact stress is 816.92 MPa

Allowable bending stress

$$\sigma_{all} = \frac{S_t Y_N}{S_F Y_\theta Y_Z} \quad (4)$$

Allowable contact stress

$$\sigma_{all} = \frac{S_t Z_N Z_W}{S_H Y_\theta Y_Z} \quad (5)$$

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Table:

Properties	20MnCr5	Grey Cast Iron
Modulus of elasticity (Gpa)	200	180
Ultimate Tensile Stress (Mpa)	650-880	770
Yield stress (Mpa)	350-550	**520**
Allowable bending stress (MPa)	173.41	244.35
Allowable contact stress (MPa)	666.09	902.57
Damping characteristic	Low	**High**

2 Material properties

The conventional steel alloy used for the gear material has disadvantages such as low specific stiffness and strength and high weight. Substituting the cast iron material for the gear have advantage of higher specific strength, less weight, high damping capacity, longer life, high critical speed and greater torque carrying capacity and can results in considerable amount of weight reduction as compared to steel. The condition for analysis has been assumed as static. For FEA analysis of Young's Modulus and Poisson's ratio for alloy steel& cast iron have been taken from design data book. Mechanical properties of the selected material were given in the Table.

1. Numerical Simulation

The stress analysis of helical gear pair is carried out by using ANSYS Workbench 16.1. The first step is to import a CATIA model in ANSYS Workbench in the IGES format. The Mesh generation plays significant role in approaching the exact result. In bending stress analysis the force is applied at the root of the tooth. While performing contact stress analysis the torque is applied at the pinion.

1.1.1. Bending Stress Analysis

The bending and contact stress analysis is performed on ANSYS Workbench 16.1. The mesh is generated by using Tetrahedron type of element in both the analysis. For bending stress analysis the tangential load is applied at the root of gear tooth, as shown in Fig. 2. The value obtained after this analysis is 90.65 MPa.

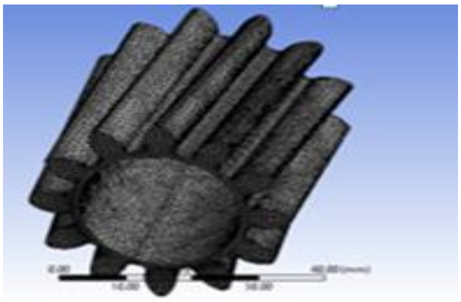

Fig.2 (a) Meshing of pinion

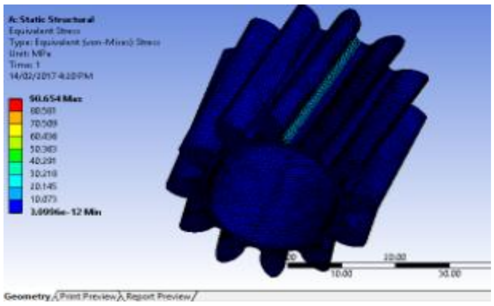

Fig.2(b) Bending Stress Analysis

The Contact stress analysis of helical gear pinion assembly is as shown in Fig. 3. The torque is applied at pinion by fixing the inner circumference area of the gear. The contact stress value obtained is 780.45 MPa.

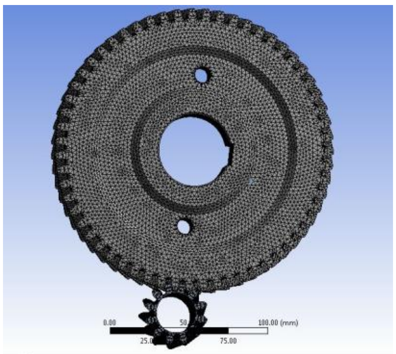

Fig. 3(c) Meshing of Helical gear pair

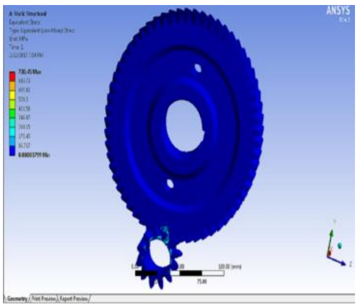

Fig. 3(d) The Contact Stress Analysis

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III. RESULTS

It is seen that the theoretical values and the ANSYS values are in good agreement. Table.3 shows the comparison between theoretical design values of bending stress with simulation values. Table.4 shows the comparison between theoretical design values of contact stress with simulation values. It is observed that even though the stress values by analytical and ANSYS analysis are close to each other the material properties do help in improving the performance. From Table.2, the allowable stress values and the dampening property of the Grey Cast Iron are good over the 20MnCr5

Table: 3 Bending stress

Material	Analytical	ANSYS
20MnCr5	87.79	90.65
Grey Cast Iron	87.79	90.65

Table: 4 Contact stress

Material	Analytical	ANSYS
20MnCr5	816.92	780.45
Grey Cast Iron	816.92	780.45

IV. CONCLUSION

The analytical stress values are calculated by using AGMA equation. The Bending stress and Contact stress analysis values of the materials are comparable however Grey Cast Iron has higher damping than the 20MnCr5. It is feasible to replace the gear material 20MnCr5 by Grey Cast Iron.

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NOTATIONS

P	Power	d_{w1}	Pitch diameter of the pinion
σ_b	Bending Stress	Z_r	Surface Condition Factor
m	Transverse metric module	Z_w	Hardness ratio factor
b	Face width	S_c	Allowable contact stress
F_t	Tangential transmitted load	Z_i	Geometry factor for contact
K_o	Overload factor	S_F	Factor of safety
K_v	Dynamic factor	Y_Θ	Temperature factor
K_s	Size factor	Y_z	Reliability factor
K_h	Load distribution factor	σ_{all}	Allowable bending stress
K_B	Rim thickness factor	S_t	Allowable bending stress
J	Geometry factor for bending strength	Y_N	Stress cycle factor for bending stress