Design Stress analysis of Metallic and Non metallic Spur Gear – A Review

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Abstract--- Gears are the very useful components in mechanical power transmission system and industrial rotating machinery. A spur gear generally subjected to two types of stresses like bending stresses and contact stresses which are causes teeth failure during meshing with another tooth. Gears are generally made from metallic materials but recently advanced polymers materials were developed which have sufficient strength and properties similar to the metallic materials so it can easily replace the metallic gears if some care will be taken. Nylon, polycarbonate, acetals and delrin are the structure polymers materials are used for gears in printing and robotics mechanism with good functionality but polymers gears are not used in heavy loading type application. Specially polymers gives extra benefits compared to metallic gears like less noise-vibration, low requirement of maintenance-lubrication, low cost and easy manufacturing. Static finite element analysis requires performing the design optimization process on both materials. This paper presents the design optimization methodology step by step for comparative analysis of metallic and polymer gears using static finite element analysis.

Keywords: - Polymer and Hybrid materials, modeling, Comparative Static finite element analysis.

I. INTRODUCTION

Gears are critical components of power transmission system and their size vary from small wrist watch gears to big rotating machinery gears. Gears are very useful due to its beneficial characteristics like constant velocity ratio and simple attachment for increase or decrease in speed of shaft so it is widely used in most of power transmission system.

According to position of shaft axis, gears classified as:

a) Parallel shaft axis
   - Spur gear
   - Helical gear
   - Rack and pinion

b) Intersecting shaft axis
   - Bevel gear

c) Non parallel non intersecting shaft axis
   - Worm gears
   - Spiral gears
   - Hypoid gears

Gears are made from following types of materials as per application.

a) Metallic materials
   - Malleable CI

b) Forged steel
   i. Carbon steel
   ii. Carbon chromium steel
   iii. Carbon manganese
   iv. Nickel chromium steel

c) Surface hardened steel

d) Case hardened steel

e) Nonmetallic and composite

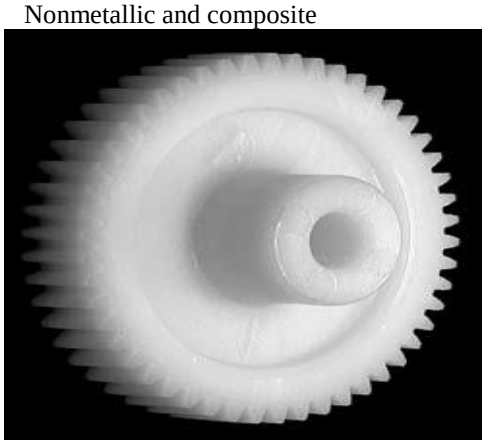


Fig. 1: Polymer gear

1. Nylon
2. acetals
3. Polycarbonate
4. Delrin

The main focus of this paper is as under.

- To understand the comparative bending stresses in different materials using static finite element analysis.
- To predict and analyze effect of loading on teeth of different material spur gear using comparative analysis.
- Check the possibility to replace metallic gear by polymer gear and viability of different material spur gear by using recent research and development.

II. LITERATURE REVIEW

The literatures mainly focus on comparative materials analysis and study possibility about replacement of metallic gears with polymers gears of light or medium power transmission system.

A. V.Siva Prasad, Syed Altaf Hussain, V.Pandurangadu, K. PalaniKumar

In this paper, Design and analysis of spur gear and proposed to subtitle the metallic gears of sugar crane juice machine with Polymer gears to reduce the weight and noise. The main purpose of this paper to analyze the different polymer gears namely nylon, polycarbonate and their viability checked with counterpart metallic gear like as cast iron. By using the FEA methodology, they concluded that composite gears, if well designed and analyzed, it will give the useful properties like as low cost, noise, weight vibration and perform its operation similar to the metallic gears.

B. Dr.Van Melick "Tooth bending effects in plastic spur gear

In this study, analysis was done by using finite element methodology for the influence of the stiffness and the

bending of plastic gear teeth due to increase in the contact path length in a considerable change in load sharing. In the preliminary and prolonged contact, the involute tooth flanks do not mesh properly, but the tooth tips make a reciprocating movement on the root of the other root.

C. Robert F. Handschuh, Gary D. Roberts, and Ryan R. Sinnamon,

Comparative FEA and experimental analysis was carried out in this study. Composite material was used as web of the gear between the gear teeth and metallic hub for the mounting to applying torque to the shaft, the web portion bonded at inner and outer hexagonal form.

This hybrid or composite gears are tested against an all steel gear. The hybrid gears operated successfully over 300 million cycles at 100 rpm and found that composite gears are 20% lighter than all steel gears. Vibration test also done on the composite gears and compared it with steel gears, results show that composite gears are produce less vibration than steel gears.

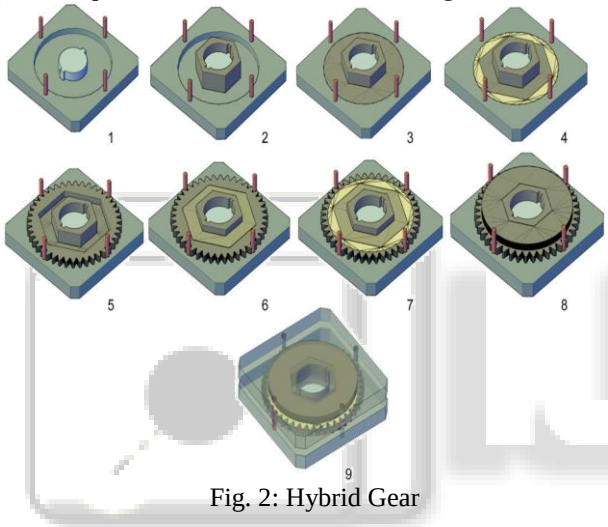


Fig. 2: Hybrid Gear

D. S. Senthilvelan and R. Gnanamoorthy,

Conduction monitoring conducted on the injection molded gears made of polymers, nylon and 20% glass filled nylon. By using Power absorption test ring, vibration and noise analysis for condition monitoring and found the possibility of early detection of gears tooth failures in case hardened spur gear. Also found that gear tooth surface temperature is increases and produce vibration at specific speed of rotation of the gears.

III. Material Specification for Spur Gear

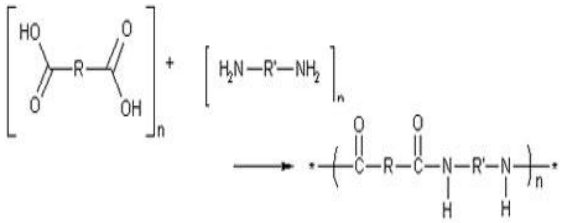
Gear materials are used according to the type of loading and torque-speed variation. Following are some conventional and non-conventional (polymer) materials with their chemical composition**.**

A. Cast iron

Carbon-2.5% to 3.7%, silicon-3.7% to 3.0%, manganese-0.5 to 1.0%, phoposorus-0.1% to 0.9%,sulphur-0.07% to 0.10%

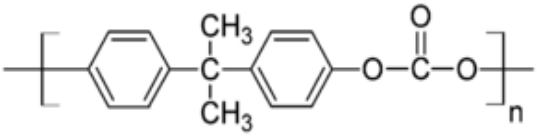
CI is used due to o its good wearing Properties, excellent machine ability and ease of producing
Complicated shapes by casting method.

B. Nylon



Properties of nylon are determine by the R and R'=6C and R=4C alkenes, but one also has to include the two carboxyl carbons in the diacid to get the number it donates to the chain.

The majorities of nylons tends to be semi crystalline and are generally very tough materials with good thermal and chemical resistance. The different types give a wide range of properties with specific gravity, melting point and moisture content tending to reduce as the nylon number increases. Nylons can be used in high temperature environments. Heat stabilized systems allow sustained performance at temperatures up to 185oC. Chemical composition of Polycarbonate:



Polycarbonates received their name because they are polymers containing carbonate groups (–O–(C=O)–O–). Most polycarbonates of commercial interest are derived from rigid monomers. A balance of useful features including temperature resistance, impact resistance and optical properties position polycarbonates between commodity plastics and engineering plastics.

IV. Design Optimization Methodology

Design optimization methodology is described as under.

A. Designing

Spur gears are design according to the power transmission rate and type of loading. Following are the various parameters of spur gear to design spur gear.

- A - Generating rack tooth addendum, (mm)
- m module
- B Generating rack tooth dedendum, (mm)
- P Power (kw)
- C Centre distance,(mm)
- c Radial clearance,(mm)
- C_s Tooth thickness coefficient
- D_b Base circle diameter, (mm)
- D_Δ Tip circle diameter,(mm)
- D_o Outside circle diameter, (mm)
- D_p Pitch diameter, (mm)
- D_r Root diameter, (mm)
- F Face width (mm)
- R_f Fillet radius (mm)
- P_d Diametral pitch (mm)

By using following procedure for calculate the gear tooth proportion of spur gear.

1. If the peripheral speeds are not given, it should be selected. For higher values of pinion speed and higher power, greater values for peripheral speed may be assumed.
2. Design transmitted load, F_t is found out.
   a. *Ft =1000*P*Co /V*
3. Where P - power to be transmitted,
   i. Co-service factor,
   ii. V - Pitch line velocity
4. Solve Lewis equation solved for module and nearest standard value is selected.
5. The approximate pinion diameter is determined form the selected value of V and the number of teeth for pinion-gear are found out.
6. Exact value for Form factor Y is calculated for pinion-gear according to pressure angle.
7. The Lewis equation is again solved for pinion-gear and to determine face width. Greater value is chosen.
8. The gears are checked and modified if need by Buckingham's equation for dynamic load and for wear to ensure that Fw ≥ fd and fb ≥ fd

Above parameters are necessary to draw a profile of gear tooth. Various techniques are used to design a spur gear like experiment based or design data book based. Various factor considered for simplicity of manufacturing and functionality of gear like machine tool and set up for manufacturing gear, cost, accuracy in tooth profile etc.

B. Modeling

A 3-d model is developed using computer software according to gear nomenclature. Pro-e, Autodesk Inventor

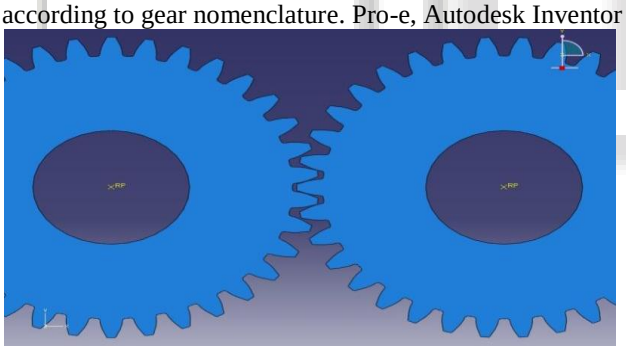


Fig. 3: Spur gear model in computer software

and solid edge are most useful modeling software. Various material properties and design data can be applied on gear model so gear behave as real one gear.

C. Analysis and optimization

Different material of a spur gear is analyzed by generally two methods.

1) Agma-lewis formula method

– *Agma formula*

$$\sigma = \frac{W_t P_d}{FJ} \cdot K_a \cdot K_s \cdot K_m \cdot K_v$$

$$\sigma_{all} = \frac{S_{at} K_L}{K_T K_R}$$

– *Lewis formula*

$$\sigma = \frac{W_t P}{bY}$$

Where

– K_a Application factor
– K_s size factor
– K_m Load distribution factor
– K_v Dynamic factor
– J Geometry factor
– P_d/P Diametral pich
– W_t Tangential load
– S_{all} Agma allowable stress
– K_L Life factor
– K_T Temperature factor
– K_R Reliability factor
– P Diametral pitch
– b- face width
– Y form factor

2) Computerized method

For analysis and optimization purpose generally ANSYS and Pro- mechanical are used to check stress-strain-deformation using a finite element analysis.

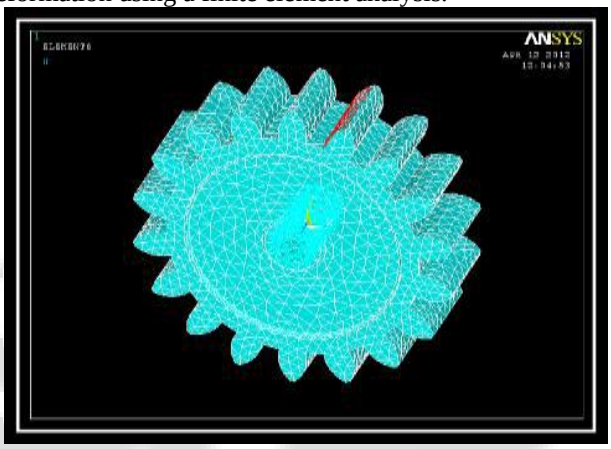


Fig. 4: Loads and boundary conditions of the gear

1. Following procedure is carried out in computer software.
2. Prepare 3D model of spur gear in modeling software.
3. Import 3D model in Analysis software, for example pro-e to Ansys.
4. Selecting type of element for meshing and desired accuracy.
5. Specify the material properties.
6. Meshing the geometry.

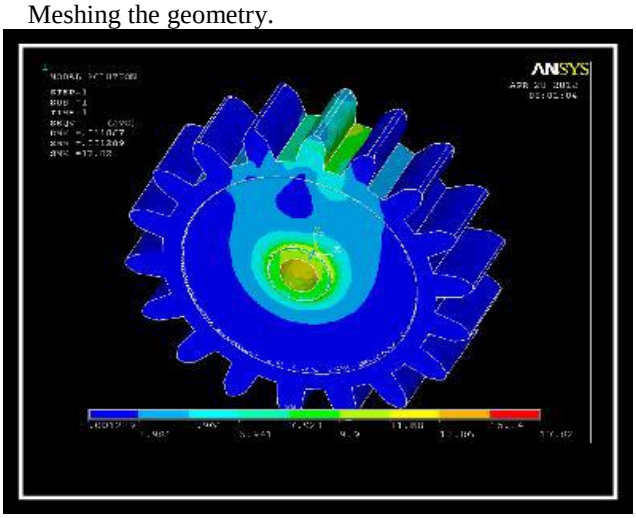


Fig. 5: stress-strain analysis

1. Applying load constraints.
2. Checking solution and plot it for comparative analysis.

V. Result Analysis Of Different Materials Spur Gear

Based on analysis of various authors, researches following statement are states as under.

- Now days, advanced polymer materials are developed which have same properties like high strength, wear resistance, less vibration and noise.
- Different structure polymers like Nylon, polycarbonate, acteal, delrin analyzed and compared to metallic gears.
- Stress-strain analysis results show that capability of replacing the metallic gears by polymer gears if sufficient care should be taken during designing.
- Composite gears are also one way to replace metallic gears by polymer gears.

VI. Conclusion

This paper gives information about design-optimization methodology to determine the comparative analysis of spur gear with different material for increase the possibility for application of polymer gears. Research and development on different material spur gear shows that if polymer are design-optimized with sufficient care, it can replace most of metallic gears to take additional benefits like low cost, easy manufacturing, low noise-vibration, low maintenance-lubrication.

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