ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

DESIGN AND ANALYSIS OF NANO COMPOSITE SPUR GEAR

R. Vigithra
Department of Mechanical Engineering, Panimalar Institute of Engineering, India
E-Mail: vigee23@gmail.com

ABSTRACT

Gears are machine elements used to transmit motion and power between rotating shafts by means of progressive engagements of projections. Gears have wide variety of applications. Their application varies from watches to very large mechanical units like the lifting devices and automotives. Engineering components made of composite materials find increasing applications ranging from space craft to small instruments. Overwhelming advantages such as light weight, higher dimensional stability and minimal attack by environment when compared with other ordinary mild steel gears. Modern level advanced polymer composite materials have opened a new level of soundless, lubricant free, high resilience and precision gearing in power and motion transmission. A proper understanding and prediction of gear failure is an important pre-requisite for any reliable application. In this project, a spur gear is designed using advanced modelling software (pro-engineer) and is meshed and analyzed using analysis software Abaqus 6.10 by the application of torque load. Two types of analysis are carried out using the software namely the static stress analysis and modal analysis. In static stress analysis tooth contact of a pair of spur gear system is analyzed as a body contact in three dimensional co-ordinates. The analysis consists of one loading condition to apply torque load on driving gear by constraining all degrees of freedom of driven gear. The hexagonal element model is meshed with in such a way that the elements around the gear teeth are fine and coarse at other places. The three dimensional elemental stresses and displacement magnitude are found out. Using modal analysis, the natural mode shapes and frequencies of composite gears is determined under free vibration. The interpretation of Eigen values which come from solving the system are that they represent the frequencies and corresponding mode shapes. The analysis is thus carried out making a comparison for a mild steel spur gear and carbon fibre / epoxy resin composite spur gear. The results in the variation of three dimensional stresses, displacement, frequencies and Eigen values are plotted and viability to manufacture such gears is predicted.

Keywords: gear, mild steel, carbon fibre, epoxy resins, Pro-engineer, modelling software.

INTRODUCTION

In this project we use a carbon fiber-epoxy resin composite material for gears. At present scenario composite gears play a vital role in low power applications such as gear motors for electromechanical actuators, gear pumps, billet roller cams, and drive shafts for car etc. Composite gears has the characteristics like corrosion resistance, wear resistance, noiseless, lubricant free, high resilience, precision gearing, high strength to weight ratio, low co-efficient of thermal expansion, high electrical conductivity etc.

THESIS OUTLINE

Development of an analysis approach and modelling procedure to evaluate stress distribution under the static condition and to evaluate the Frequencies and Eigen values under vibrational loads would provide a useful tool to improve composite spur gear design with high efficiency and low cost. Based on the theories of gear meshing and contact analysis, a three dimensional finite element model of spur gear system was established to investigate stress distribution. The most of work has summarized as follows:

- Analysis of spur gear designed considering the material properties of steel and varying the torque load.
- Analysis of spur gear designed considering the material properties of carbon fiber and epoxy resin composite material with the number of layers as five and varying the torque load.
- Conducting modal analysis of spur gear designed for determining the frequencies and eigen mode shapes by considering the material properties of steel for gear
- Conducting modal analysis of spur gear designed for determining the frequencies and Eigen mode shapes by considering the material properties of carbon fiber and epoxy resin composite material for gear.

SCOPE OF THE PROJECT WORK

Gears made from a rigid material such as metal or metal alloys are well known and are used in many applications. These gears withstand with high torque load forces, but have a significant in that they generate a great noise when they mesh with other metal gears.

Gears made from a thermoplastic material are well known, and have been used to reduce the noise generated by metal gears. The disadvantages in thermoplastic gears have great significant, in which they cannot withstand high torque load forces without damaging the gear teeth, and are more susceptible to wear than metal gears.

To solve the respective problems of metal and thermoplastic gears, the no of attempts have been made to manufacture composite gears. In this project, the three dimensional stress results are carried out by the application of varying torque load forces for the carbon fiber and epoxy resin composite material.

INTRODUCTION ABOUT CARBON FIBERS

The material consisting of extremely thin fibers about nano size of 0.0005–0.010 mm in diameter and composed mostly of carbon atoms. Carbon fiber, or Graphite fiber, carbon graphite or CF of the carbon atoms are mixed and bonded together in microscopic crystals that are more or less aligned parallel to the long axis of the fiber. The crystal position and alignment makes the fiber very strong for its size. Several thousand carbon fibers are bonded and twisted together to form a yarn, which may be used by own or woven into a fabric.

The properties of carbon fibers such as high tensile strength, high flexibility, high temperature tolerance, low weight, and low thermal expansion make them very popular along with other sports competition also in Mechanical, structural, aerospace, civil engineering, military, and motor world. However, they are relatively very expensive when compared to same common similar fibers for example plastic fibers or glass fibers.

To form a composite, Carbon fibers are usually combined with other materials. When combined with a plastic fibre resin and wound or molded it forms carbon fiber reinforced plastic (often referred to also as carbon fiber) which is extremely rigid, a very high strength-to-weight, although somewhat brittle in nature. However, carbon fibers are also composed with other materials, such as with graphite to form carbon in one layer and carbon in next layers carbon composites, which have a very high heat withstanding and tolerance.

Carbon fibers are a new breed of high-strength materials. Carbon fiber has been debuted as a fiber containing at least 90% carbon obtained by the controlled pyrolysis of appropriate fibers. The carbon fiber is existed from 1879 when Edison took out a patent for the manufacture of carbon filaments suitable for use in electric lights and bulbs However, when successful commercial production was started in early 1960s, as it was required in the aerospace industry - especially for military aircraft - it was important to bring light weight materials became of paramount. In recent decades, carbon fibers have been established in wide application in commercial and, industrial, military aircraft, recreational and transportation markets. Carbon fibers are used in nano composites with a lightweight matrix. Carbon fiber composite materials are suited to applications where high strength, stiffness, less in weight, and outstanding fatigue characteristics are critical requirements. They also can be used in the special occasion where high temperature, chemical inertness and high damping are given as most important factors.

TYPES AND CLASSIFICATION

Based on modulus, strength and final heat treatment temperature, Nano carbon fibers are classified into the following categories:

Based on properties carbon fibers are classified into:

- UHM (ultra high modulus). Modulus of elasticity > 65400 ksi (450GPa).
- HM (high modulus). Modulus of elasticity is in the range 51000-65400 ksi (350-450GPa).
- IM (intermediate modulus). Modulus of elasticity is in the range 29000-51000 ksi (200-350GPa).
- HT (high tensile, low modulus). Tensile strength > 436 ksi (3 GPa), modulus of elasticity < 14500 ksi (100 GPa).
- SHT (super high tensile). Tensile strength > 650 ksi (4.5GPa).

Based on precursor fibre materials, nano carbon fibers are classified as:

- PAN-based carbon fibres.
- Pitch-based carbon fibres.
- Mesophase pitch-based carbon fibres.
- Isotropic pitch-based carbon fibres.
- Rayon-based carbon fibres.
- Gas-phase-grown carbon fibres.

Based on final heat treatment temperature, Nano carbon fibers are classified as:

Type-I: High-Heat-treatment (HTT) nano carbon fibers, where final heat treatment temperature should be more than 2000°C and can be associated with high-modulus type fiber.

Type-II: Intermediate-Heat-Treatment (IHT) Nano carbon fibers, the final heat treatment temperature should acheive around or above 1500°C and can be associated with high-strength type fiber.

Type-III: Low-heat-treatment (LHT) Nano carbon fibers, where the final heat treatment temperatures not cross greater than 1000°C. These are low modulus and low strength materials.

CHARACTERSTICS OF CARBON FIBER

Carbon fibers are characterized by the following properties:

- Light weight;
- High strength-to-weight ratio;
- Too High modulus elasticity-to its-weight ratio;
- High fatigue strength;
- Good corrosion resistance;
- Too less coefficient of thermal expansion;
- Low impact resistance;
- High electric conductivity;
- High cost.

APPLICATIONS OF CARBON FIBERS

The main applications of carbon fibers are in specialized technology, which includes military, aerospace and nuclear engineering, and in common engineering and in transportation, which includes engineering components such as bearings, bushes, gears, cams, fan blades and automobile bodies. Recently, some new applications of nano carbon fibers have been found. Such as rehabilitation of a bridge [8] in building and construction industry. Others include: decoration in automotive industries, marine, aviation interiors, entertainment and musical instruments and after-market transportation products. Conductivity in electronics technology provides additional new application. Table-1 illustrates some of the characteristics and application of carbon fiber.

DEFINE MESH

How to mesh the gear teeth part is the key research area during contact analysis of the spur gear, especially the gear tooth position of root part is easiest to appear in the stress concentration. For saving time of gear simulation and ensuring the calculation accuracy, FEM meshes with a region of the contact area is small and FEM mesh in the region apart from the contact area is large.

The hexahedron has the higher computation precision than the tetrahedron, so the model applies to the hexahedron as the mesh element. However, this particular model cannot apply the hexahedron by naturally. Therefore, gear can be separated along the root circle. The high number seed in the gear contact face and the axis is defined. The given element type as 3D stress is applied at the same time. (C3D8R)

Gears are meshed and contacted with hexa element in such a way that the elements around the gear teeth are fine and coarse at other places.

Element type: CHEXA
No. of elements: 39160

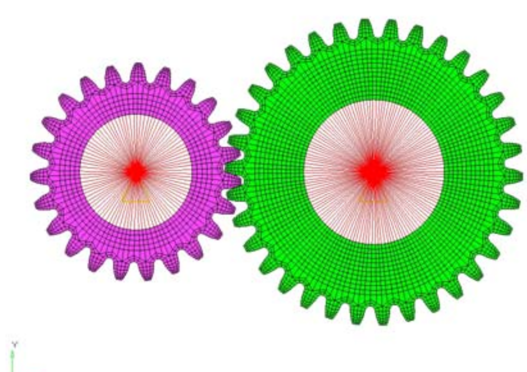


Figure-1. Meshing of spur gear set.

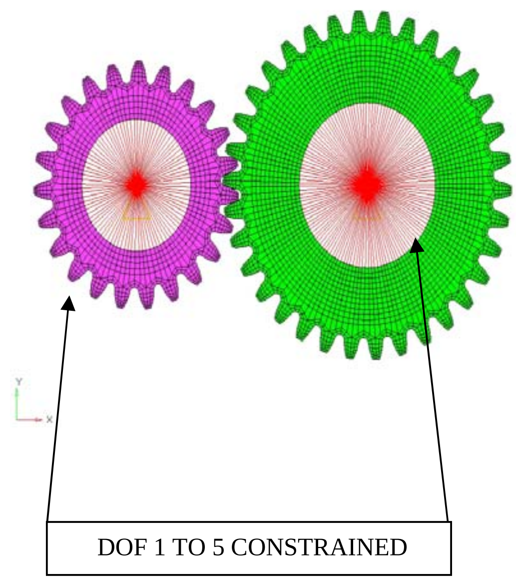


Figure-2. Boundary condition applied during analysis.

RESULT

This model chapter is submitted to analyze, if it is not able obtain the result, the software should be changed for corresponding modification based on the showing result. We can examine the final output and carry on the analysis. If this model runs successfully and obtains the corresponding analysis result at last.

MODAL ANALYSIS OF SPUR GEARS

DEFINITION OF MODAL ANALYSIS

While it is being designed Modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component. It also can be considered as a starting point for another, more detailed, dynamic analysis can be used , such as a transient dynamic analysis is the first, a harmonic response analysis is second , or a spectrum analysis as last.

OVERVIEW OF STEPS IN MODAL ANALYSIS

The procedure for a modal analysis consists of four main steps:

- Build the model
- Apply loads and obtain the solution
- Extract the modes
- Review the results

BUILD THE MODEL

Specify the job name and analysis title and then define the element types, element real constants, material properties and the model geometry. These tasks are common as the static stress analysis

- Only linear behavior is valid in a modal analysis. If we are specifying nonlinear elements, they are probably treated as linear. For example, if you

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

include contact elements, their stiffness's are calculated based on their initial status and never change.

- Material properties can be listed as linear, isotropic or orthotropic, and constant or temperature-dependent. You must define both Young's modulus (EX) (and stiffness in some form) and density (DENS) (or mass in some form) for a modal analysis. Nonlinear properties must be ignored.

APPLY LOADS AND OBTAIN THE SOLUTION

Apply the analysis type and options, then apply loads, specify load step options, and begin the finite element solution for the different natural frequencies given. After the initial solution, we can expand the mode shapes for review.

Table-1. Analysis types and analysis options.

Option	Path
New analysis	Solution- analysis type – new analysis
Analysis type	Modal analysis
Mode extraction method	Solution – analysis options – subspace method
Number of modes to extract	Solution – analysis options – 6

The subspace method is used for large symmetric eigenvalues problems. Several solution controls are available to control the subspace iteration process. When doing a modal analysis with a large number of constraint equations, use the subspace iterations method with the frontal solver instead of the JCG solver, or use the block Lanczos mode extraction method.

REVIEW THE RESULTS

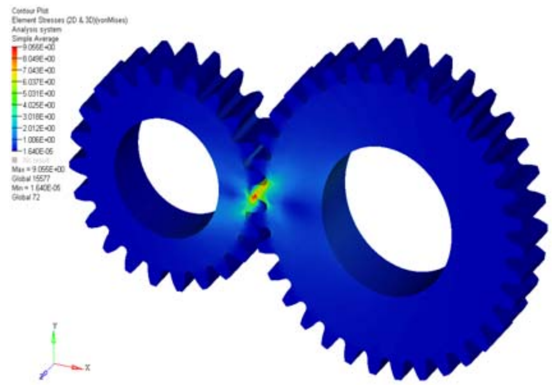
The natural frequencies and mode shapes are obtained after applying the loads (self weight).this procedure is repeated for the steel spur gears and carbon fiber/epoxy resin composite spur gears.

STATIC STRESS ANALYSIS RESULTS

Carbon fiber/epoxy resin composite spur gear

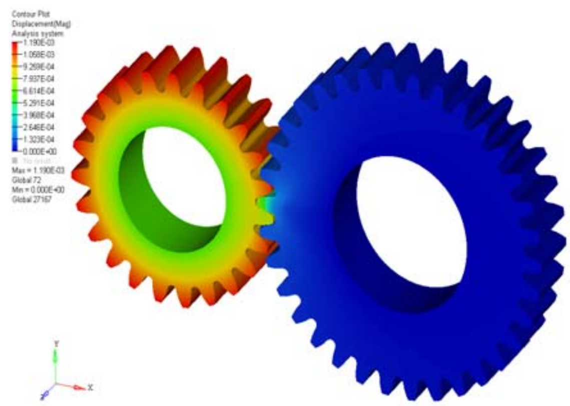
MODE	FREQUENCY (Hz)	LOAD STEP	SUBSTEP	CUMULATIVE
1	9.353	1	1	1
2	629.75	1	2	2
3	1786.57	1	3	3
4	1800.157	1	4	4
5	1829.17	1	5	5
6	1855.99	1	6	6

Case-1: Torque load applied IS 10000N-mm



VON misses stress contour result for 10N-m.

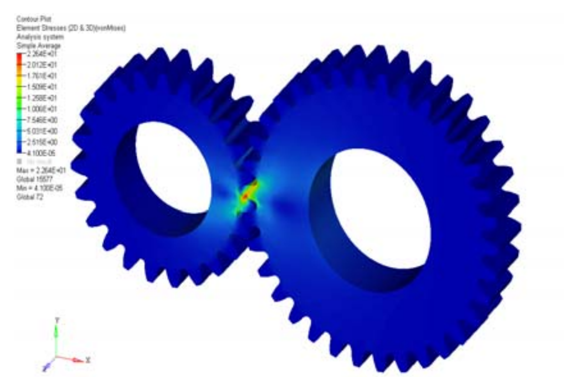
Maximum stress value is 9.055 MPa for a torque load of 10N-m.



Displacement contour results for 10N-m.

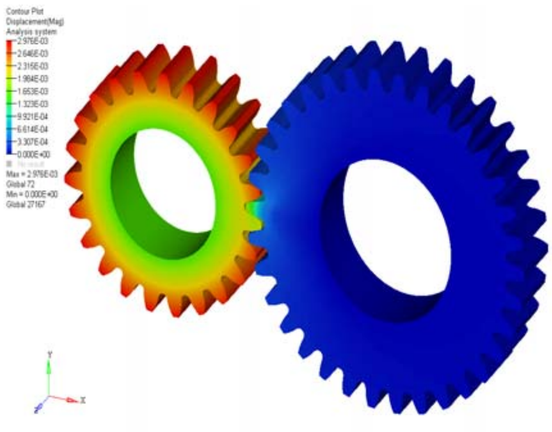
Maximum displacement value is 0.00119m for a torque load of 10N-m.

Case-2: When torque load applied IS 25N-m



VON misses stress contour result for 25N-m.

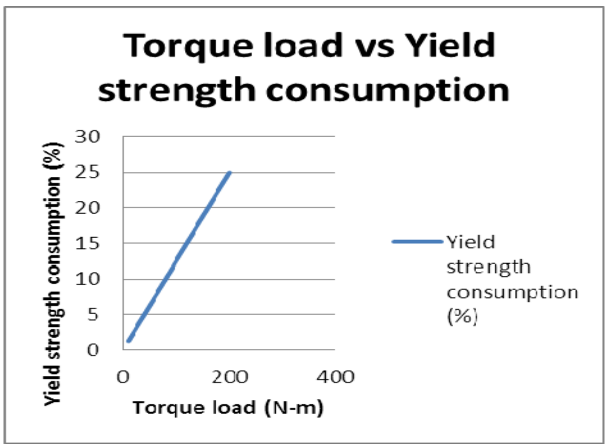
Maximum stress value is 22.6MPa for a torque load of 25N-m.



Displacement contour results for 25N-m.

Maximum displacement value is 0.002976m for a torque load of 25N-m.

Natural frequencies of steel spur gear



Torque load vs. yield strength consumption for composite spur gear.

DISCUSSIONS

The displacement values for carbon fiber-epoxy resin spur gear is much less when compared to the steel spur gear when torque load is being applied

- The three dimensional stress (von misses stress) values are comparatively very less for carbon fiber-epoxy resin for Nano composite spur gears
- The consumption of yield strength is very much less in the case of carbon fiber-epoxy resin composite spur gears when compared to the steel spur gears
- From the modal analysis of two spur gears it is understood that the natural frequency of carbon fiber-epoxy resin composite spur gear is very high when compared to steel spur gears.

CONCLUSIONS

- From the above results it is partially concluded that the steel spur gears can be replaced with the carbon fiber-epoxy resin composite spur gear in future for power transmission. These composite materials not only find applications in the manufacture of gears but also in many other places like high strength epoxy adhesives used in fabrication of carbon fiber composite drive shafts for cars, low power applications such as gear motors for electromechanical actuators, gear pump, billet roller cams etc.

- When compared to the steel spur gears the percentage weight reduction is nearly 50 percent and has many more characteristics such as corrosion resistance, wear resistance, noiseless, lubricant free, high resilience, precision gearing, high strength to weight ratio, low co-efficient of thermal expansion, high electric conductivity etc. The only drawback with the carbon fiber-epoxy resin composite spur gear is the cost of manufacturing is very high

REFERENCES

[1] S. S. Maheedhara and F. Pourboghrat. 2007. Finite element analysis of composite worm gears, Journal of Thermoplastic Composite Materials, Vol. 20, January.

[2] Jaroslav Mackerle. 2003. Finite element analysis and simulation of quenching and other heat treatment process Abibliography (1976-2001), Computation materials science Vol. 27, pp. 313-332.

[3] Prášil, Ludvík, Mackerle and Jaroslav. 2008. Finite element analyses and simulations of gears and gear drives. A bibliography 1997-2006, Engineering Computations: International Journal for Computer-Aided Engineering and Software, Vol. 25, No. 3, pp. 196-219.

[4] Vijaya Kumar Ambarisha and Robert G. Parker. 2007. Nonlinear dynamics of planetary gears using analytical and finite element models, Journal of sound and vibration Vol. 302, pp. 577-595.

[5] Kahraman A., Kharazi A. A., Umrani M. 2003. A deformable body dynamic analysis of planetary gears with thin rims, Journal of sound and vibration, Vol. 262, pp. 752-768.

[6] S. S. Maheedhara and F. Pourboghrat. 2007. Finite element analysis of composite worm gear, Journal of thermoplastic composite materials, Vol. 20, January.

[7] Lin Tengjiao, Ou H., Li Runfang. 2007. A finite element method for 3D static and dynamic contact/impact analysis of gear drives, Computer Methods in Applied Mechanics and Engineering, Vol. 196, No. 9-12 (February 1), pp. 1716-1728.

[8] Rehabilitation Bridges: Carbon Fiber-reinforced Polymer Shows Promise for Repairing.

[9] Structures. 1999. Advanced Materials & Composites News, No. 2.

[10] Deepa Nair. 2005. Gear Modeling by Simulating The Fabrication Process, Master thesis, University of Cincinnati.

[11]. http://www.ptc.com/products/proengineer/

[12]. Abaqus/CAE User's Manual

[13].www.utm.edu/departments/engin/lemaster/Machine%20Design/Lecture%2021.pdf.

[14]. Norton R. L. 1992. Machine Elements in Mechanical Design, 2nd ed., Merrill, New York, USA.

[15]. Bernard J. Hamrock, Bo Jacobson and Steven R. Schmid. 1999. Fundamentals of Machine Elements, McGraw-Hill.