Stress Analysis of Composite Spur Gear

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ABSTRACT

This paper investigates the static stress characteristics of an involute composite spur gear system including bending stresses and contact stresses of gears in mesh and comparing it with the existing involute cast iron spur gear system. The aim is to replace the cast iron spur gear with Carbon fibre epoxy composite spur gear due to its high strength, low weight and damping characteristics. A pair of involute spur gear is modelled in a CAD system (PRO/ ENGINEER) and FEA is done by using finite element software ANSYS 13. The bending stresses in the tooth root and contact stresses were examined using a 3-D FEM model. The bending stress obtained by finite element analysis method is compared with bending stress obtained by Lewis equation and the contact stress obtained by finite element analysis method is compared with contact stress obtained by Hertzian equation.

2. INTRODUCTION

Gearing is one of the most critical components in a mechanical power transmission system, and in most industrial rotating machinery. Many high-performance power transmission applications (e.g., automotive and aerospace) require low weight [6], [15], [19]. The two primary failure modes of gears are, one by tooth breakage from excessive bending stress and other by surface pitting or wear from excessive contact stress [9]. The conventional spur gears are continuously being investigated in order to reduce the failure or increase their transmissible power level, either by developing new composite materials [6], [7], [11] or by modifying the gear tooth geometry[16], [19], [20], [21], [22]. Carbon fibre epoxy has high strength and less density compared to cast iron and steel [7], [11], [15]. Short carbon fiber reinforced epoxy gear fabricated by properly controlled injection molding processes can provide higher strength and better performance and often exhibit less wear rate [10].

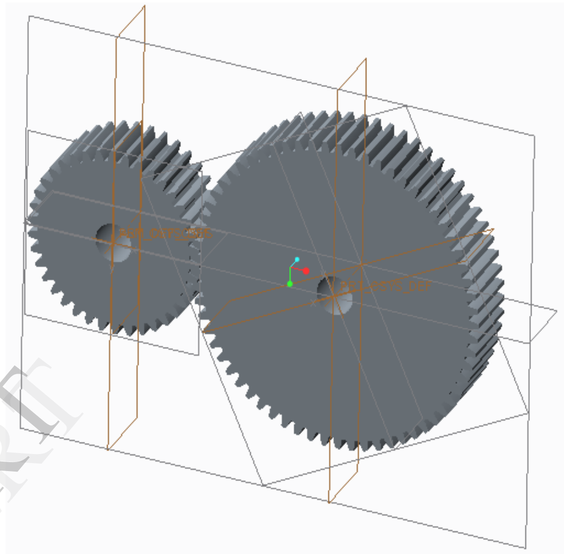
3. MODELLING OF SPUR GEAR

The Driving and driven gear are the most important components of the Gear box of any automotive. Modeling allows the design engineer to let the characteristic parameters of a product drive the design of that product. During the gear design, the main parameters that would describe the designed gear such as module, pressure angle, root radius, and tooth thickness, number of teeth could be used as the parameters to define the gear.

Gear geometry

Parameter	Driving Gear	Driven Gear
Profile	Involute	Involute
Module (mm)	3	3
Pressure angle (deg)	20	20
No. of teeth	38	65
PCD(mm)	114	195
Addendum circle diameter	120	201
Base circle diameter	106.8	187.8
Root circle Diameter(mm)	106.5	187.5
Center Distance(mm)	154.5	154.5
Face Width(mm)	42	42
Tooth thickness(mm)	4.7124	4.7124

The finite element method is proficient to supply this information but the time required to generate proper model is a large. Therefore to reduce the modelling time a pre-processor method that builds up the geometry required for finite element analysis may be used, such as Pro/Engineer. Pro/Engineer can generate three dimensional models of gears. The generated model geometry in Pro/Engineer is opened in ANSYS for analysis.



4. BENDING STRESS - LEWIS EQUATION

Bending failures in gears is predicted by comparing the calculated bending stress to experimentally-determined allowable fatigue values for the given material. This bending stress equation was derived by Wilfred Lewis [1], [2]. Lewis considered gear tooth as a cantilever beam with static normal force F applied at the tip of the tooth. Lewis equation to calculate bending stress is,

$$\sigma_b = \frac{F_t}{bYm}$$

Where, F_t = Tangential Force,

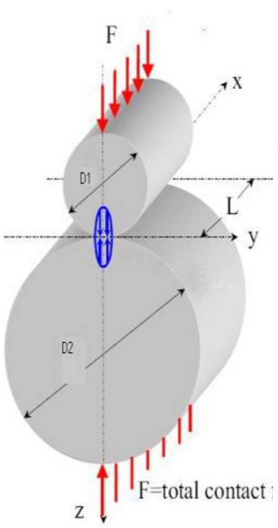
b = Face width of tooth,

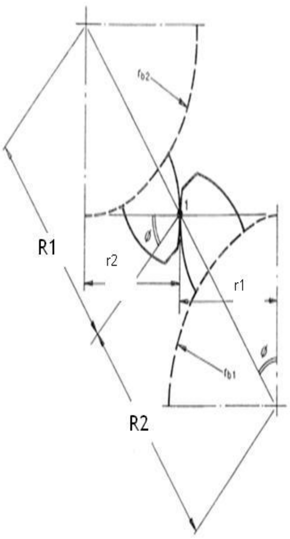
Y = Lewis form factor

m = Module.

5. CONTACT STRESS - HERTZIAN EQUATION

Contact failure in gears is currently predicted by comparing the calculated Hertz contact stress to experimentally determined allowable values for the given material. Hertz treated a pair of gear teeth as two cylinders of radii equal to the radii of curvature of the mating involutes at the pitch point [1], [2]. Contact stress is a compressive stress occurring at the point of maximum Hertzian stress.





The maximum contact stress/ Hertz stress/ Compressive stress/ Contact pressure,

$$P_{max} = \sigma_H = \frac{4F}{\pi BL}$$

Where, Contact width

$$B = \sqrt{\frac{8 \times F}{\Pi \times L} \times \frac{\frac{1-\nu 1^2}{E_1} + \frac{1-\nu 2^2}{E_2}}{\frac{1}{D_1} + \frac{1}{D_2}}}$$

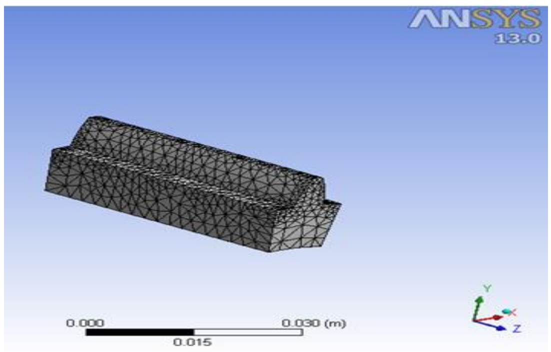
Where, F = Applied Force

D_1 & D_2 = Diameters of the gears,

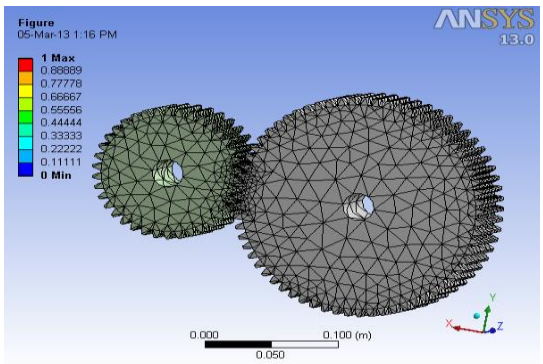
E1 & E2 = Modulii of Elasticity of gear materials,

ν_1 & ν_2 = Poisson's ratios of gear materials.

6. MESH GENERATED FOR FEA



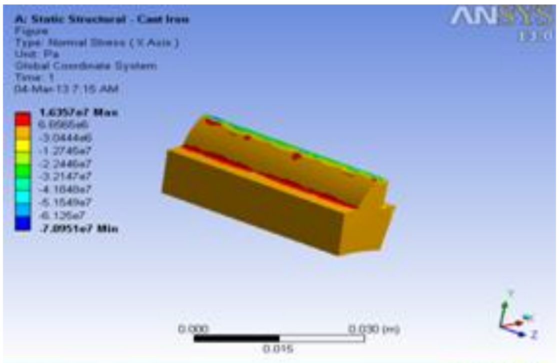
Meshing for bending stress analysis

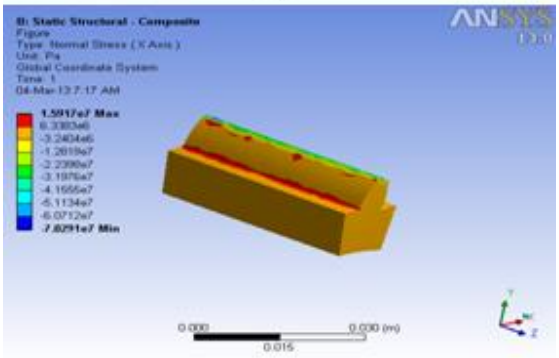


Meshing for contact stress analysis

7. RESULTS

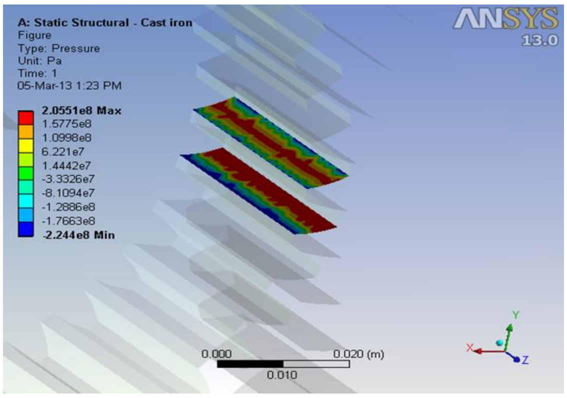
7.1. BENDING STRESS ANALYSIS

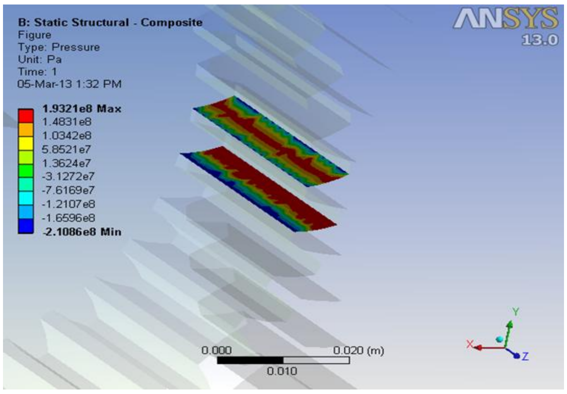




Material	Maximum Stress Induced (MPa)	
	Analytical Procedure	FEM Numerical Procedure
Cast Iron	15.27	16.36
Carbon fibre epoxy composite	15.27	15.92

7.2. CONTACT STRESS ANALYSIS





Material	Maximum Stress Induced (MPa)	
	Analytical Procedure	FEM Numerical Procedure
Cast Iron	200	205.51
Carbon fibre epoxy composite	188.51	193.21

8. CONCLUSION

The objective of current work is to replace the cast iron spur gear with carbon fibre epoxy composite spur gear. For that, analytical and finite element method are applied for determining bending stresses and contact stresses of gear tooth. The obtained FEA results is compared with the analytical results and found that both results are comparable. Result shows that by both stress analysis the strength of the carbon fiber reinforced epoxy spur gear made by 90 degree fibre orientation of laminates is more when compared with cast iron spur gear . Also the density of the carbon fiber reinforced epoxy is very less when compared with cast iron spur gear. So we can conclude that the cast iron spur gear can be replaced by Carbon fiber reinforced epoxy (composite) spur gear due to its high strength, low weight and damping characteristics.

9. REFERENCES

1. Joseph. E. Shigley, Charles. R. Mischke, Richard. G. Budynas, Keith. J. Nisbett, 'Mechanical Engineering Design', Tata McGraw Hill, Eighth Edition 2010, pp. 653-755.

2. Gitin. M. Maitra, 'Handbook of Gear Design', Tata McGraw Hill, Second Edition 2010, pp. 1.1-1.21 & 2.1-2.147.

3. L.S. Srinath, 'Advanced Mechanics of Solids', Tata McGraw Hill, Third Edition 2009, pp. 97-121 & 374-427.

4. Robert. M. Jones, 'Mechanics of Composite Materials', Taylor & Francis, Second Edition 1999.

5. Faculty of Mechanical Engineering, PSG College of Technology, 'Design Data – Data book of engineers', July 2003.

6. V. Siva Prasad, Syed Altaf Hussain, V. Pandurangadu, 'Modeling and analysis of spur gear for sugarcane juice machine under static load condition by using FEA', International Journal of Modern Engineering Research (IJMER), Vol.2, No.4 (2012), pp.2862-2866.

7. S. Vijayarangan, N. Ganesan, 'Stress analysis of composite spur gear using the finite element approach', Computers & Structures, Vol. 46, No.5 (1993), pp.869-875.

8. Zhong Hu, Mohammad Robiul Hossan, 'Strength evaluation of short carbon fiber reinforced polymeric composite spur gears by finite element analysis', Composites Science and Technology, Vol.36, No.4 (2011), pp. 2021-2029.

9. Seok-Chul Hwang, Jin-Hwan Lee, Dong-Hyung Lee, Seung-Ho Han, Kwon-Hee Lee, 'Contact stress analysis for a pair of mating gears', Mathematical and Computer Modelling, Vol.57 (2013), pp. 40–49.

10. N.A. Wright, S.N. Kukureka, 'Wear testing and measurement techniques for polymer composite gears', Wear Vol.251 (2001), pp.1567–1578.

11. S. Vijayarangan, N. Ganesan, 'Static stress analysis of a composite bevel gear using a three dimensional finite element method', Computers & Structures, Vol.51, No. 6 (1994), pp.771-783.

12. Prashanth Banakar, H.K. Shivananda, 'Preparation and characterization of the carbon fiber reinforced epoxy resin composites', IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE) Vol.1, No.2 (2012), pp.15-18.

13. Prince, Mukesh Verma, Sarabjot Singh, 'Analysis of failure phenomena in multi-fiber polymer composite material at varying volume fraction using finite element modeling', International Journal of Engineering Research and Applications (IJERA) , Vol.2, No.2 (2012), pp.287-291.

14. S. Senthilvelan, R. Gnanamoorthy, ' Damping characteristics of unreinforced, glass and carbon fiber reinforced nylon 6/6 spur gears', Polymer Testing, Vol.25, No.1 (2006), pp. 56-62.

15. Jane Maria Faulstich De Paiva, Alexandre De Nadai dos Santos, Mirabel Cerqueira Rezende, Mechanical and morphological characterizations of carbon fiber fabric reinforced epoxy composites used in aeronautical field', Materials Research, Vol.12, No.3 (2009), pp. 367-374.

16. Hayrettin Duzcukoglu, Huseyin Imrek, 'A new method for preventing premature pitting formation on spur gears', Engineering Fracture Mechanics, Vol.75, No.15 (2008), pp. 4431-4438.

17. Sabah M.J. Ali, Omar. D. Mohammad, 'Load sharing on spur gear teeth and stress analysis when contact ratio changed', Al-Rafidain Engineering, Vol.16, No.5 (2008), pp. 11-16.

18. Evgeny Podzharov, Vladimir Syromyatnikov, Julia Patricia Ponce Navarro and Ricardo Ponce Navarro, 'Static and dynamic transmissin error in spur gears', The Open Industrial and Manufacturing Engineering Journal, Vol.1 (2008), pp.37-41.

19. David. F. Thompson, Shubhagm Gupta, Amit Shukla, 'Tradeoff analysis in minimum volume design of multi-stage spur gear reduction units', Mechanism and Machine Theory, Vol.35 (2000), pp. 609-627.

20. Shanmugasundaram Sankar, Nataraj, Maasanamuthu Sundar Raj, 'Profile modification for increasing the tooth strength in spur gear using CAD', Scientific Research – Engineering, Vol. 2 (2010), pp. 740-749.

21. M. S. Hebbal, V. B. Math, B. G. Sheeparamatti, 'A Study on reducing the root fillet stress in spur gear using internal stress relieving feature of different shapes', International Journal of Recent Trends in Engineering, Vol.1, No. 5 (2009), pp.163-166.

22. Laurentia Andrei, Gabriel Andrei, Alexandru Epureanu, Iulian Gabriel Birsan, 'Synthesis and analysis of plastic curved facewidth spur gears', Tribology, Vol.1 (2005), pp. 193-198.