Bending and Free Vibration Analysis of Carbon Nanotube Reinforced Composite Spur Gear (CNTRCG) Using Finite Element Method

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1. INTRODUCTION & OBJECTIVE

Composites are the most popular and important materials used in various fields nowadays due to its advantages and better performances and this makes a new way for the world to become less depending on the usage of conventional materials. The present study discusses the bending and free vibration behavior of carbon nanotube reinforced composite gear (CNTRCG) with different carbon nanotube fiber reinforcement orientations using finite element method. The finite element formulation is based on first-order shear deformation theory (FSDT) [1]. The present formulation is coded in MATLAB and validated with available literature.

The effective material properties for the nanocomposites are determined from the engineering constants using the rule of mixture [2]. Vijayarangan & Ganesan [3] described the bending analysis of composite spur gear using FEM approach. Maiti & Sinha [4] studied the bending and free vibration analysis of shear deformable laminated composite beams using finite element method. P. Zhu et al. [5] described the static and free vibration analyses of carbon nanotube reinforced composite plates using finite element method with FSDT. Four types of CNT reinforcements are considered with different volume fractions for CNT (V^{*}_{CNT}). The present study shows the effect of CNT fiber orientation on static deflection and free vibration behavior of composite gears. The present FE formulation also emphasis on effective calculation of material properties with respect to fiber orientation in gears. Figure 1 shows the gear tooth sector with reinforcements.

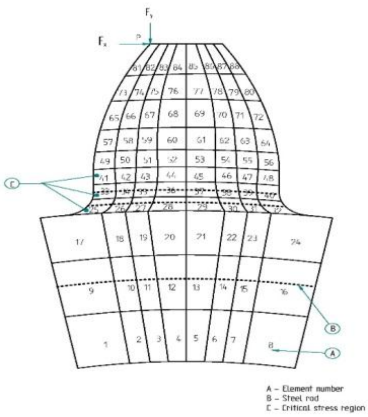

Figure 1: Gear Tooth sector with reinforcements

2. RESULTS & HIGHLIGHTS OF IMPOINTANT POINTS

For each of the orientation of carbon nanotube fibers, finite element analysis of nanocomposites gear tooth is carried out. The gear tooth is modeled based on the orientation of carbon nanotube fiber reinforcement. The finite element code is developed to calculate the deflections and natural frequencies for polymer and composite gears. The present FE code is validated with available literature results for its accuracy and the same are presented in Tables 1-2. From Tables 1-2, it is found that the present FE code results agree well with those of literature. The present FE code is further used for analysis of different gear configurations. Table 3 shows the bending stress calculated for conventional gear (polymer gear) using design data hand book [6] from Lewis equation and present FE code and the present FE results are smaller than those of analytical values.

Table 1: Comparison of non-dimensionalised displacements and fundamental frequencies for laminated cantilever beam.

a/h	**Fiber orientation (Degree)**	**Displacements ($\bar{w}_0$)**		**Natural frequency (λ)**	
		Present FEA	**Maiti [3]**	**Present FEA**	**Maiti[3]**
60	0	2.9240	2.9265	13.0571	12.9941
	30	15.6671	17.1231	5.3602	5.3926
	45	26.5586	28.3620	4.2126	4.1808
	60	34.8721	36.0543	3.7442	3.7060
	90	39.9906	40.0831	3.5336	3.5155

Table 2: Comparison of non-dimensional central deflections and natural frequencies for CNTRC simply supported plate under UDL

V^*_{CNT}		**Center Deflections ($\bar{w}$)**		**Natural frequency (ω)**	
	b/h	**Present FEA**	**P. Zhu et al.[4]**	**Present FEA**	**P. Zhu et al.[4]**
0.11	10	0.0036	0.0037	13.5956	13.532
	20	0.0353	0.0362	17.4973	17.355
	50	1.1045	1.1550	19.5823	19.223

Table 3: Analytical bending stress calculation comparison

Analytical Results in N/mm^2	**FE Results in N/mm^2**	**% of Error**
88.0905	79.4783	10.8359

In the present work, the bending and free vibrational analysis is presented to investigate the mechanical behavior of spur gear made up of different materials like polymer, Composite materials: Fiber reinforced composites and Nano fiber reinforced composites. Each of the above said gear is subjected to bending load at the tip of gear tooth.

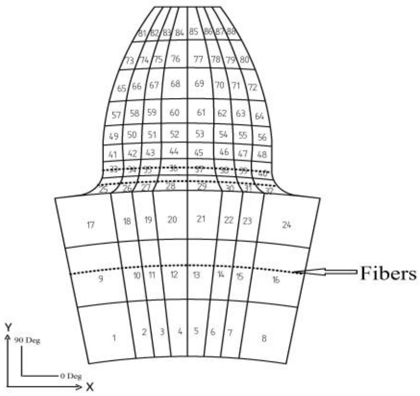

Figure 2: Gear Tooth sector with fiber reinforcement axis and orientations.

Table 4 presents the deflections and natural frequencies for spur gear modeled with three different materials. From Table 4, it can be seen that the tip deflection is maximum for the gear made of conventional material like polymer than the other two reinforcing techniques. Composite gear with fiber reinforced at different fiber orientations, the tip deflection reduces gradually and it becomes less for 90^0 fiber orientation. Hence considering the 90^0 orientation case separately, gear tooth tip deflections are obtained by varying the tooth thickness for size and weight optimization of the composite gear.

Table 5 shows that the gear tooth tip deflections for fiber reinforced composite gear and CNTRCG by varying gear tooth thickness. For conventional gear with tooth thickness t = 10 m gives 1.9864 mm tip deflections whereas for FRCG with tooth thickness t=3.05 m gives 1.9730 mm tip deflection and for NFRCG with tooth thickness t = 2.2 m gives 1.9807 mm for same load. Hence it can be concluded that the conventional polymer gear with 10m can be replaced by either 3.05 m FRC gear or 2.2 m NFRC gear, which would result in considerable reduction of weight and size of the gear while retaining the same strength. The present results show the proposed FRC and NFRC gears are promising future power transmissions systems. Further the study is extended to investigate stresses induced in the critical section of the composite spur gear teeth.

Table 4: Deflections and Natural Frequencies for Spur Gear

Conventional Gear (Polymer Gear)		**Composite Gear**				
		Fiber Reinforced Composite Gear (FRCG)			**Nano Fiber Reinforced Composite Gear (NFRCG)**	
Deflection (mm)	**Natural Frequency (Hz)**	**Fiber orientation (Degree)**	**Deflection (mm)**	**Natural Frequency (Hz)**	**Deflection (mm)**	**Natural Frequency (Hz)**
1.9864	29.4110	0	1.5561	29.1936	1.5982	29.4867
		30	1.5647	30.8329	1.5606	32.6203
		45	1.3522	33.8793	1.2551	37.9153
		60	1.0184	38.8193	0.8447	45.5183
		90	0.6018	47.1763	0.4358	49.6296

Table 5: Deflections and Natural Frequencies for Spur Gear for varying tooth thickness

Thickness (module m)	**Composite Gear**	
	Fiber Reinforced Composite Gear (FRCG)	**Nano Fiber Reinforced Composite Gear (NFRCG)**
	Deflection (mm)	**Deflection (mm)**
10.00	0.6018	0.4358
9.00	0.6686	0.4842
8.00	0.7522	0.5447
7.00	0.8597	0.6225
6.00	1.0029	0.7263
5.00	1.2035	0.8715
4.00	1.5044	1.0894
3.05	**1.9730**	1.4525
2.50	2.4070	1.7430
2.20	2.7353	**1.9807**

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