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Transient Study of Functional Graded Composite Spur Gear (FGCSG) with FEA

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Abstract: Article focuses on brief literature review of composite gears, in which the attention is focused on the behavior of laminated composite gear with various fiber reinforcement arrangements. Because of their favorable conditions and better exhibits, functional composites are the most commonly used and important materials in a number of fields, paving the way for the world to become less dependent on the use of traditional materials. The broad field of nano composites and gear are very briefly discussed. Transient analysis of composite spur gear literatures available has been reviewed. The need for the composite fiber reinforced plastic gear is presented. Using the FE technique, the current study investigates the transient behavior of traditional material apparatus, fiber fortified rigging, and carbon nanotube reinforced composite apparatus (CNTRCA) with different carbon nanotube fiber fortification directions. The latest outcomes of fiber reinforced composites and nanofiber reinforced apparatuses are exciting rigging drives for potential force and movement transmission applications. The FE technique is based on the theory of first shear twisting theory (FSDT). The current description is written in open writing and coded in MATLAB. Optimization of reinforcement of fiber in critical section of gear is studied and in turn weight to stiffness ratio can be improved.

Keywords: Functional, Nanofibers, CNTRCA, FSDT

1. Introduction

Automobiles, spacecraft, and wind turbines are all examples of significant engineering applications of gears. Energy transmission components have been installed in the majority of their initial lifespan. Most power-driven procedures have one or more gear systems, such as block and tackle to revolve the barrel and cams to control alterations in laundry machineries; processor copier's winches to suckle and control production; copiers, Programmed Cashier Machineries have various gear drives components. Enactments of polymers gears are designed by a team of investigators, and preparations are made to model the interaction conditions by gear drive in sequence. These applications need little maintenance, need no lubrication, and are superior to all basic gear designs. Based on these considerations, the load carrying ability of polymer gears must be increased by improved material properties, and they must be compared to metal gears. Nano fibers with orientation can be reinforced to strengthen material properties. In recent years, design discovery of space, civic constructions, and compound material development have all raised interest. Composite Polymer Matrix (CPM) mechanisms or gears often had a tough time recovering from drawback, beginning with when the lone uses for plastic gears were developed in puppets and in noncritical application. Functional graded composite material (FGCM) has a variety of applications, ranging from moving large amounts of spinning force to precise placement of delicate machineries in medical and aerospace parts. FGCM gears have a number of advantages, including design tractability, high power-to-mass and toughness-to-mass ratios. FGCM gear systems are more agile, quieter, have less friction, and are more resistant to erosion. This has a plethora of applications, including locomotives, liquidizers, electrical engineering, feeder energies, and food handling. In this study, the problem will be modelled with FEA using the FSDT in first order [1].

By changing the layup and fiber positions, compound resources can be tailored to meet particular durability and power requirements. Calculating the material properties of CNT using the rule of mixture [3] is used to characterize the twisting and uninhibited vibration investigation of carbon nanotube fortified composite gear using the FE strategy [2]. The versatile analysis of gear with numerical method was defined by Vijayarangan & Ganesan [4]. Maiti and Sinha [5] used FEA to investigate the versatile and free pulsation properties of shear deformable layered compound beams. The effect of tiny fiber reinforcements on the contraction efficiency of tiny fiber strengthening nylon 66 injection moulded complex gearing spur is investigated [6]. Overall volumetric contraction in molded gears is minimized by integrating tiny thermoplastic 66 resin glass fibres [7]. FEM and FSDT were used by Zhu et al [8] to characterize the carbon nanotube reinforced complex plates.

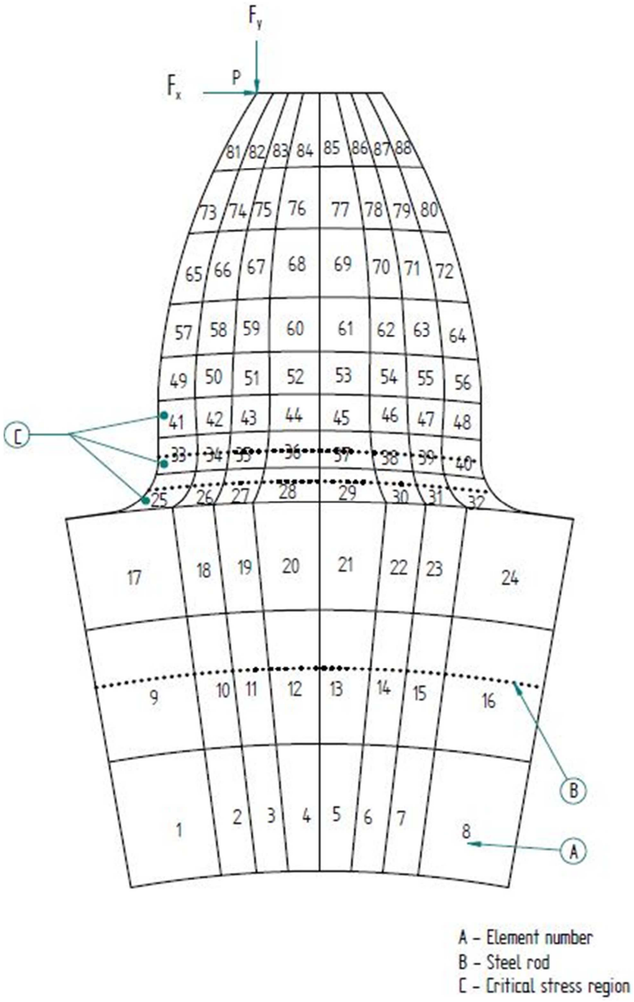

Figure 1. Geometry of the tooth with reinforcements.

Carbon Nanotube Reinforced Composite Spur Gear (CNTRCG) Bending and Free Vibration Analysis Using Finite Element Method is studied by Shravankumar and Nagaraj [9] Analysis of the static and transient behaviour of fibre reinforced composite spur gear (FRCG) is described by Shravankumar and Nagaraj [10]. Hoskins et al. [11] used a twin-disc test rig to conduct tests without external lubrication over a range of loads and slip ratios, studying the wear and friction mechanisms of composite gears. K. Mao et al. [12] focused their research on machine cut acetal gear wear and thermal mechanical contact behaviour. Nozawa et al. [13] carried out a study on the tribology of nylon 66/phenylene ether polymer sheets adhered to steel gear teeth. Rao et al. [14] used ANSYS to design a composite gear and investigate the thermal effects, displacement, and contact stresses in the gear tooth.

The effect of carbon nanotube fiber alignment on the transient output of functional graded composite gears is discussed in this paper. The gear tooth geometry is shown in Figure 1. In the depth way, the nanofibers are thought to be uniformly spaced. For the FGCM gear, the CNT impacts bulk portion, limit circumstances, and ratio between width and thickness on transient reactions are debated. Mathematical results are linked to previous work, and there is reasonable agreement.

The rule of mix is incorporated in the current learning by adding the CNT adequacy variables, and the genuine physical properties of CNTRC apparatus can thus be recorded as, due to its simplicity and reasonableness.

$$\begin{aligned} E_{11} &= \eta_1 V_{CNT} E_{11}^{CNT} + V_m E^m \\ \frac{\eta_2}{E_{22}} &= \frac{V_{CNT}}{E_{22}^{CNT}} + \frac{V_m}{E^m} \\ \frac{\eta_3}{G_{12}} &= \frac{V_{CNT}}{G_{12}^{CNT}} + \frac{V_m}{G^m} \end{aligned} \tag{1}$$

Where E_{11}^{CNT}, E_{22}^{CNT}, G_{12}^{CNT}, E^m and G^m designate the elastic and shear moduli of CNT's and properties of the isotropic medium respectively.

2. Fea Formulation

The FEA procedure is developed using eight node isoparametric elements based on FSDT, each with five degrees of freedom (DOFs), as pictured in Figure 2. An 8-knot quadrate component, the form functions are:

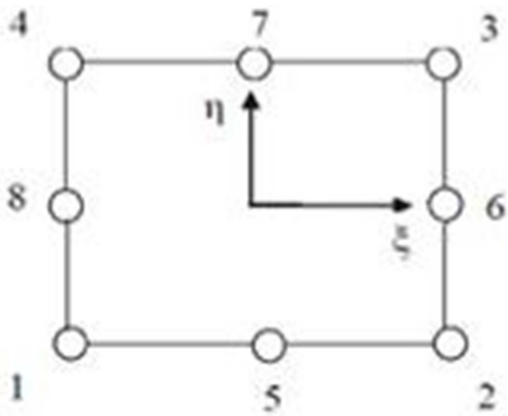

Figure 2. Eight node element.

$$\begin{aligned} N_1 &= 0.25*(1-\zeta)*(1-\eta)*(-1-\zeta-\eta) \\ N_2 &= 0.5*(1-\zeta)*(1-\eta^2) \\ N_3 &= 0.25*(1+\zeta)*(1-\eta)*(-1+\zeta-\eta) \\ N_4 &= 0.5*(1+\zeta)*(1-\eta^2) \\ N_5 &= 0.25*(1+\zeta)*(1+\eta)*(-1+\zeta+\eta) \\ N_6 &= 0.5*(1-\zeta^2)*(1+\eta) \\ N_7 &= 0.25*(1-\zeta)*(1+\eta)*(-1-\zeta+\eta) \\ N_8 &= 0.5*(1-\zeta)*(1-\eta^2) \end{aligned} \tag{2}$$

Straining power (Π) for the element is known by equation,

$$\begin{aligned} \Pi &= \frac{1}{2}\int \sigma^T \varepsilon\, dv \\ &= \frac{1}{2}\iiint \varepsilon^T D\varepsilon\, dx\,dy\,dz \end{aligned} \tag{3}$$

Where the straining vector $\{\varepsilon\}$ is known as,

$$\{\varepsilon\} = \{\varepsilon_x \;\; \varepsilon_y \;\; \gamma_{xy}\} \tag{4}$$

The translation functions (u, v, w) at a point (x, y, z) for FSDT are expected as follows

$$\begin{aligned} u(x,y,z) &= u_0(x,y) + z\theta_x(x,y) \\ v(x,y,z) &= v_0(x,y) + z\theta_y(x,y) \\ w(x,y,z) &= w_0(x,y) \end{aligned} \tag{5}$$

The parameters u_0, v_0, w_0, θ_x and θ_y are the plane in the middle translations & revolutions. The rigidity matrix is defined as,

$$[K_e] = \int_{A_e} [S]^T [ABD][S]\, dA \tag{6}$$

$$[ABD] = \begin{bmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} \\ A_{12} & A_{22} & A_{26} & B_{12} & B_{22} & B_{26} \\ A_{16} & A_{26} & A_{66} & B_{16} & B_{26} & B_{66} \\ B_{11} & B_{12} & B_{16} & D_{11} & D_{12} & D_{16} \\ B_{12} & B_{22} & B_{26} & D_{12} & D_{22} & D_{26} \\ B_{16} & B_{26} & B_{66} & D_{16} & D_{26} & D_{66} \end{bmatrix} \tag{7}$$

Where $[A]$ - the in-plane toughness matrix, $[B]$ - the coupler matrix and $[D]$ - the flexible matrix and are,

$$\begin{aligned} [A] &= \sum_{k=1}^{n} \int_{z_k}^{z_{k+1}} \left[Q_{xy}^k\right] dz \\ [B] &= \sum_{k=1}^{n} \int_{z_k}^{z_{k+1}} \left[Q_{xy}^k\right] z\,dz \\ [D] &= \sum_{k=1}^{n} \int_{z_k}^{z_{k+1}} \left[Q_{xy}^k\right] z^2\,dz \end{aligned} \tag{8}$$

The reduced stiffness matrix $[Q]$ is prearranged by

$$[Q] = \begin{bmatrix} Q_{11} & Q_{12} & Q_{16} \\ Q_{21} & Q_{22} & Q_{26} \\ Q_{61} & Q_{62} & Q_{66} \end{bmatrix} \tag{9}$$

Where

$$Q_{11} = \frac{E_{11}}{1-\nu_{12}\nu_{21}},\; Q_{22} = \frac{E_{22}}{1-\nu_{12}\nu_{21}},\; Q_{12} = \frac{\nu_{21}E_{11}}{1-\nu_{12}\nu_{21}},\; Q_{66} = G_{12}$$

The component mass matrix is given by,

$$[M_e] = \int_{A_e} \int_{-h/2}^{h/2} [N]^T [\rho][N]\, dz\,dA \tag{10}$$

The mass density matrix may be inscribed as,

$$[\rho] = \begin{bmatrix} I & O & O & H & O \\ O & I & O & O & H \\ O & O & I & O & O \\ H & O & O & T & O \\ O & H & O & O & T \end{bmatrix} \tag{11}$$

Where

$$(I, H, T) = \int_{-h/2}^{h/2} (1, z, z^2)\rho(z)\, dz \tag{12}$$

Through gathering all the component mass matrix, $[M_e]$ and stiffness matrix, $[K_e]$, with respect to the global coordinates, the following is attained,

For static analysis the calculation is

$$[K]\{d\} = \{F\} \tag{13}$$

For free pulsation analysis the equation is

$$[M]\{\ddot{d}\} + [K]\{d\} = \{F\} \tag{14}$$

Where $\{d\}$ is the translation vector

$\left\{\ddot{d}\right\}$ is the acceleration vector

$\{F\}$ is the force vector

$[K]$ and $[M]$ are the global stiffness and mass matrices

Newmark (Numerical) Time Integration

In the Newmark technique, the function (of time) and its derivative are estimated by means of Taylor's sequence and are specified by,

$$\left\{\Delta\left(t_{i+1}\right)\right\}=\left\{\Delta\left(t_i\right)\right\}+\delta t_i\left\{\dot{\Delta}\left(t_i\right)\right\}+\frac{1}{2}\left(\delta t_i\right)^2\left\{\ddot{\Delta}\left(t_{i+\gamma}\right)\right\} \tag{15}$$

$$\left\{\dot{\Delta}\left(t_{i+1}\right)\right\}=\left\{\dot{\Delta}\left(t_i\right)\right\}+\delta t_i\left\{\ddot{\Delta}\left(t_{i+\alpha}\right)\right\} \tag{16}$$

$$\left\{\ddot{\Delta}\left(t_{i+\alpha}\right)\right\}=(1-\alpha)\left\{\ddot{\Delta}\left(t_i\right)\right\}+\alpha\left\{\ddot{\Delta}\left(t_{i+1}\right)\right\} \tag{17}$$

Where δt is the increase in time, $\delta t_i = t_{i+1} - t_i$, & t_i is existing (initial) time and t_{i+1} is the subsequent time at which need resolution. Put Eq. (17) into Eq. (15) and Eq. (16) and resolving for $\left\{\ddot{\Delta}\right\}$,

$$\begin{aligned}\left\{\dot{\Delta}\right\}_{i+1}&=\left\{\dot{\Delta}\right\}_i+a_1\left\{\ddot{\Delta}\right\}_i+a_2\left\{\ddot{\Delta}\right\}_{i+1}\\ \left\{\ddot{\Delta}\right\}_{i+1}&=a_3\left(\{\Delta\}_{i+1}-\{\Delta\}_i\right)-a_4\left\{\dot{\Delta}\right\}_i-a_5\left\{\ddot{\Delta}\right\}_i\end{aligned} \tag{18}$$

Where,

$$\begin{aligned}&a_1=(1-\alpha)\delta t_s,\ a_2=\alpha\delta t_s,\ a_3=\frac{2}{\gamma\left(\delta t_s\right)^2},\\ &a_4=a_3\delta t_s,\ a_5=\frac{(1-\gamma)}{\gamma}\end{aligned} \tag{19}$$

α and γ are the coefficients to be chosen.

3. Results and Discussion

The transitory action reinforced composite gears of carbon nanotubes is discussed in this chapter. PmPV [9] is the matrix used in the analysis. Table 1 lists the material properties used in the analysis.

FE investigation of study of functional graded composites gear tooth is described for each of the directions of carbon nanotube filaments. Depending on the path of carbon nanotube fiber fortification, the apparatus tooth is shown. The transient response of plastic and composite gears is studied using a finite element code. Open works vouch for the accuracy of the existing formulation, which are presented in Tables 2–3 and Figure 3. The current results of FE code are well agreed with the results of works. It is established that. The current formulation is extended to various the gear configurations, as well as the boundary conditions for the analysis (pictured in Figure 4) are given as $u = v = w = \theta_x = \theta_y = 0$. The current effort describes a transient study to examine the performance of gear modelled with polymer, composite materials: fiber reinforced composites, and nanofiber reinforced composites.

Table 1. *Analytical Material Properties.*

E_{1cnt} (TPa)	5.6466
E_{2cnt} (TPa)	7.0800
NU_{12cnt}	0.175
G_{12cnt} (TPa)	1.9445
Rho_{cnt} (g/cm3)	2.0
E_m (GPa)	2.1
G_m (GPa)	0.7836
NU_m	0.34
Rho_m (g/cm3)	1.15

Table 2. *Cantilever beam validation for laminated composite.*

Fiber orientation (Degree)	Deflections (w_0)		Deflections (w_0)		Deflections (w_0)	
	a/h=60		a/h=20		a/h=10	
	Current FEA	Maiti [4]	Current FEA	Maiti [4]	Current FEA	Maiti [4]
0	12.9996	12.9940	12.8002	12.6450	8.4641	8.4913
30	5.5318	5.3926	5.4319	5.3374	3.7680	3.5301
45	4.2595	4.1815	4.2074	4.1627	2.9149	2.7678

Table 3. *Correlation between non-dimensional focal distractions and typical CNTRC plate frequencies.*

V^*_{CNT}	b/h	focus redirection ($\bar{w}$)		Natural frequency (ϖ)	
		Current FEA	Ping et al.[5]	Current FEA	Ping et al.[5]
0.14	10	0.0033	0.00331	14.1030	14.3060
	20	0.0300	0.0300	18.7078	18.9210
	50	0.8978	0.9180	21.3721	21.3540

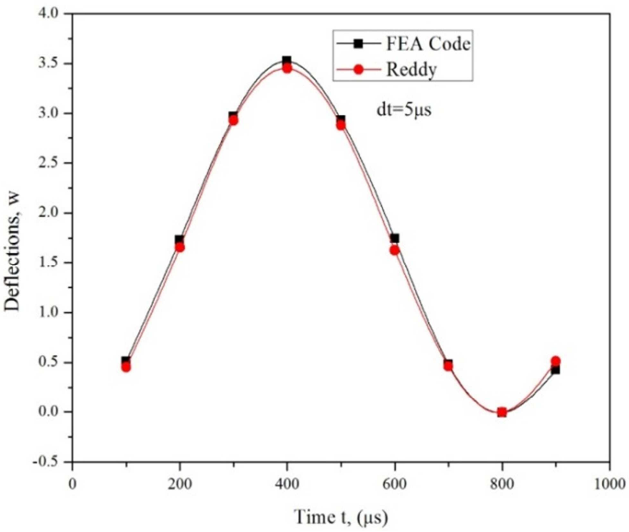

Figure 3. *Comparison of non-size transverse deflection (w) against time (t) for antisymmetric cross-ply (0/90) simply-supported (SS-1) laminates that have been uniformly distributed.*

The transient deflections for utilitarian assessed prod gear are shown in Figures 5–9. Three different materials are used to view the transient deflections. From these figures it tends to be seen that transitory deflection is more extreme than the other two strengthening policies for the apparatus made of customary material such as polymer. The deflection of the head is slowly decreasing, and for 90° fiber direction, the composite rigging with fiber reinforced in several directions is less. From now on, the gear tooth tip deflections are acquired separately, given that the tooth thickness for compositional apparatus is different in size and weight.

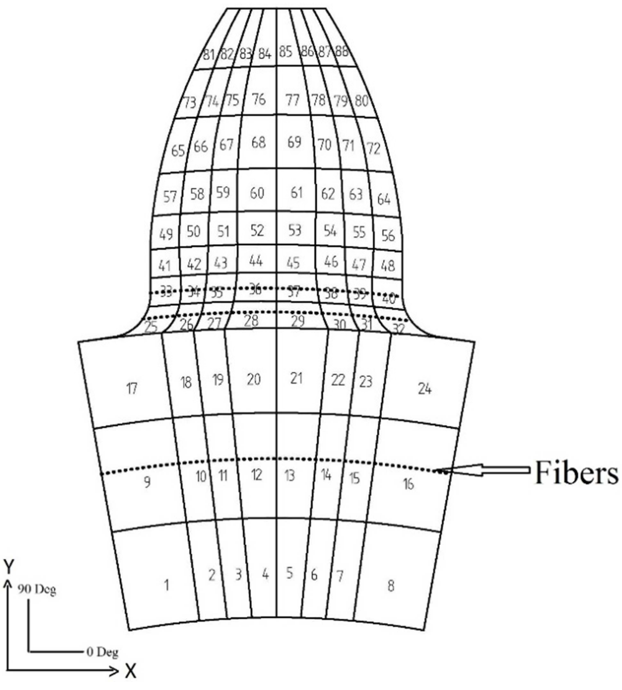

Figure 4. *Apparatus tooth area with fiber support hub and directions.*

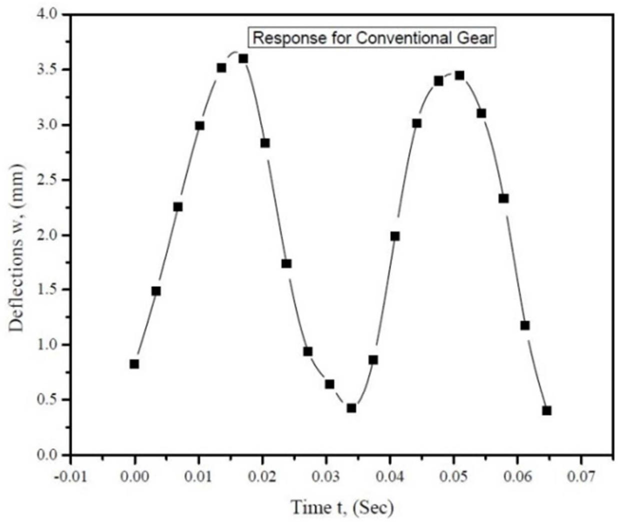

Figure 5. *Conventional Polymer Gear Transient Response.*

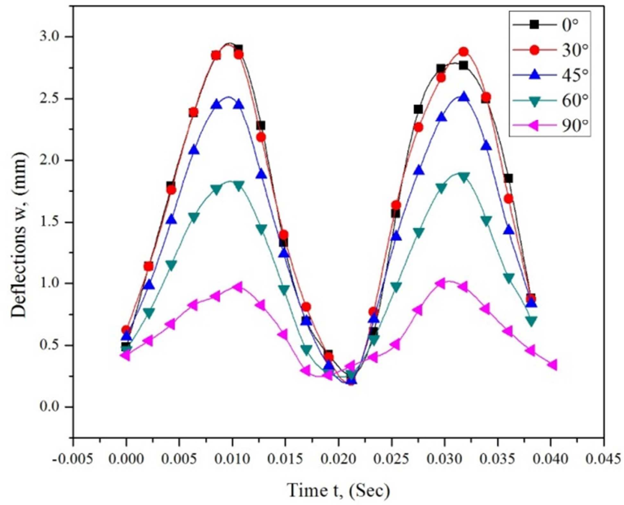

Figure 6. *Fiber Reinforced Composite Gear Transient Response*

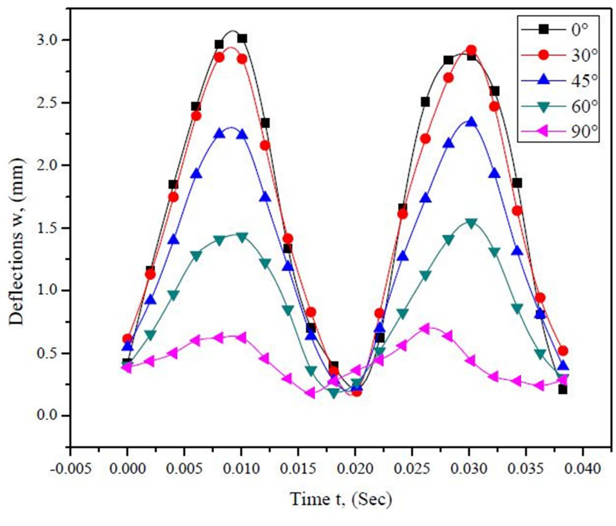

Figure 7. *Carbon Nanotube Reinforced Composite Gear Transient Response.*

For the same load, conventional apparatus thickness of tooth t=10 m results in 3.6024 mm deviation of the tip, FGRCG thickness of tooth t=3.05 m results in 3.3392 mm tip deflections, and NFGRCG with tooth thickness t=2.2 m results in 3.1862 mm tip deflections. As a result, it is commonly assumed that standard polymer gear with thickness of 10m can be replaced with either 3.05m FRC equipment or 2.2 m NFRC gear, resulting in a significant reduction in weight and size of the rigging while maintaining comparable efficiency. According to current results, the proposed FRC and FRC Gears are promising future force transfer frameworks.

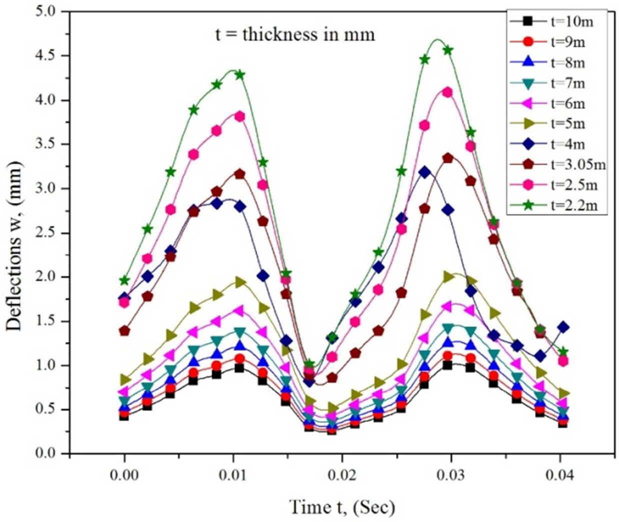

Figure 8. *FRC Gear with Varying Thickness Transient Response.*

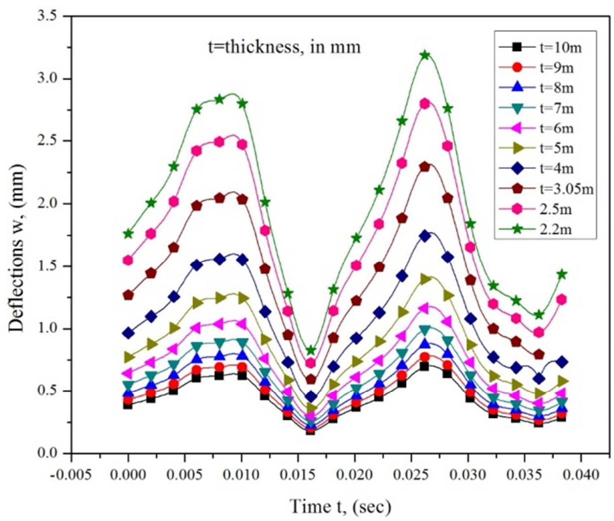

Figure 9. *CNTRC Gear with Varying Thickness Transient Response.*

4. Conclusions

The following important inferences are drawn from the mathematical studies conducted for spur gear transient vibration analysis:

1) Based on the numerical outcomes, it's clear that nanofiber complex resources can also be used as a power transmission material.
2) The firmness/quality of the rigging teeth could be improved by strengthening the nanofibers in the teeth.
3) The development of mathematical code effectively demonstrates FEA formulation of compound gear. In addition, the mathematical code for reinforcing nanofibers in the gear has been established efficiently.
4) Future force transmission frameworks may use fiber reinforced composite and nanofiber fortified composite riggings.

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The corresponding author declares that there is no conflict of interest on behalf of all authors.

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