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Determination of Vibration Characteristics of Carbon Nanobeams

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Abstract-*This paper deals with the dynamic behavior of nano carbon beam. Our study is to analyze the frequencies normal carbon nano beams used in the reinforcement of Civil Engineering structures often subjected to vibration loads due to seisms. The vibration characteristics of nano beams are studied without including deformation due to shear and to rotational inertia. On the one hand we introduce the effects of the shear deformation due to shear and rotational inertia for the accurate prediction of natural frequencies.*

Keywords – Carbon nanotubes (DWNT), Stiffness, beam, vibration, amplitudes, frequencies.

1.0 INTRODUCTION

Carbon nanotubes type (DWNT) are used for (nanoelectronics, nanodevices and nanocomposites [1]), due to their characteristic electronic, mechanical, and other physical and chemical properties. The mechanical behavior (DWNT) was the subject of many recent research studies. Since nanoechelles experiments are difficult, and molecular dynamics simulations remain expensive and particularly great for large scale systems, the continuum of the elastic models have been widely used successfully to study the mechanical behavior (DWNT), as the bending [2], thermal vibration [3], the resonance frequencies and modes [4]. In this part, the resonant frequencies are studied and the vibrational modes of a carbon nanotube types DWNT embedded in an elastic medium. The analysis is based on a model of multiple beam elastic. The elastic medium exerts a pressure by hypothesis p per unit length along the x axis, acting on the outer tube; this pressure is due to the surrounding of the elastic medium. This model is to model the surrounding environment as a result of independent identical springs and reaction module k_1. Thus, the medium exerts a restoring force density equal to $-k_1\omega$, where the negative sign indicates that the pressure $c_1(\omega_2-\omega_1)$ is opposite to the deflection of the outer tube, and is a constant determined by the material constants of the elastic medium, the diameter outside of incorporated DWNTs, k_1 and the wavelength of the vibration modes. (Figure 1)

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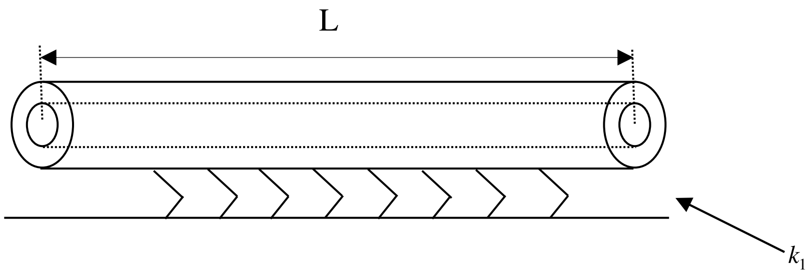

Figure 1: Vibration of a (DWNT) embedded in an elastic medium characterized by a stiffness of the flexibility

2.0 THE EQUILIBRIUM EQUATIONS

$$c_1(\omega_2-\omega_1)=EI_1\frac{\partial^4\omega_1}{\partial x^4}+\rho A_1\frac{\partial^2\omega_1}{\partial t^2}+EA_1\theta T\frac{\partial^2\omega_1}{\partial x^2}-(e_0a)^2[\rho A_1\frac{\partial^4\omega_1}{\partial x^2\partial t^2} + EA_1\theta T\frac{\partial^4\omega_1}{\partial x^4}-c_1\frac{\partial^2(\omega_2-\omega_1)}{\partial x^2}] \quad (1)$$

$$-k_1\omega_2-c_1(\omega_2-\omega_1)=EI_2\frac{\partial^4\omega_2}{\partial x^4}+\rho A_2\frac{\partial^2\omega_2}{\partial t^2}+EA_2\theta T\frac{\partial^2\omega_2}{\partial x^2} -(e_0a)^2[\rho A_2\frac{\partial^4\omega_2}{\partial x^2\partial t^2}+EA_2\theta T\frac{\partial^4\omega_2}{\partial x^4}+k\frac{\partial^2\omega_2}{\partial x^2}+c_1\frac{\partial^2(\omega_2-\omega_1)}{\partial x^2}] \quad (2)$$

These two differential equations describe the transverse free vibration-type carbon nanotubes (DWNTs) with the initial stress, and coupled together by the interaction of Van der Waals. When the effect of the short length and the initial stress is ignored, the equations (1) and (2) are reduced to the classical result for local carbon nanotubes kind (DWNT) [5].
k_1 : Stiffness of the flexibility

3.0 DETERMINATION OF MODES

Consider the double tubes carbon nanotubes (DWNTs) of length L for which both ends are simply supported, the vibration modes of DWNTs are written in the form [6]

$$\omega_1=a_1e^{i\omega t}\,sin(\frac{n\pi x}{L}) \quad (3)$$

$$\omega_2=a_2e^{i\omega t}\,sin(\frac{n\pi x}{L}) \quad ;\ \text{With } (n=1\ ;\ 2\ ;\ 3\ldots\ldots) \quad (4)$$

Where's a_1 and a_2 the bending amplitudes of internal and external tubes. Thus, the two frequencies of order n with the initial stress DWNT resonance can be obtained through the nonlocal model substituent .In equations (3) and (4) in equations (1) and (2), we obtain [7]

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$$
\begin{aligned}
& c_1(a_2 e^{i\omega t}\sin(\frac{n\pi x}{L}) - a_1 e^{i\omega t}\sin(\frac{n\pi x}{L})) = EI_1\frac{a_1 e^{i\omega t}\sin(\frac{n\pi x}{L})n^4\pi^4}{L^4} \\
& -\rho A_1 a_1\omega^2 e^{i\omega t}\sin(\frac{n\pi x}{L}) + EA_1\theta T\frac{a_1 e^{i\omega t}\sin(\frac{n\pi x}{L})n^2\pi^2}{L^2} \\
& -(e_0 a)^2[\rho A_1\frac{a_1\omega^2 e^{i\omega t}\sin(\frac{n\pi x}{L})n^2\pi^2}{L^2} + EA_1\theta T\frac{a_1 e^{i\omega t}\sin(\frac{n\pi x}{L})n^4\pi^4}{L^4} \\
& +c_1\frac{a_2 e^{i\omega t}\sin(\frac{n\pi x}{L})n^2\pi^2}{L^2} - c_1\frac{a_1 e^{i\omega t}\sin(\frac{n\pi x}{L})n^2\pi^2}{L^2}]
\end{aligned} \tag{5}
$$

$$
\begin{aligned}
& -k_1 a_2 e^{i\omega t}\sin(\frac{n\pi x}{L}) - c_1(a_2 e^{i\omega t}\sin(\frac{n\pi x}{L}) - a_1 e^{i\omega t}\sin(\frac{n\pi x}{L})) = \\
& EI_2\frac{a_2 e^{i\omega t}\sin(\frac{n\pi x}{L})n^4\pi^4}{L^4} - \rho A_2 a_2\omega^2 e^{i\omega t}\sin(\frac{n\pi x}{L}) \\
& +EA_2\theta T\frac{a_2 e^{i\omega t}\sin(\frac{n\pi x}{L})n^2\pi^2}{L^2} - (e_0 a)^2[\rho A_2\frac{a_2\omega^2 e^{i\omega t}\sin(\frac{n\pi x}{L})n^2\pi^2}{L^2} \\
& +EA_2\theta T\frac{a_2 e^{i\omega t}\sin(\frac{n\pi x}{L})n^4\pi^4}{L^4} - k_1\frac{a_2 e^{i\omega t}\sin(\frac{n\pi x}{L})n^2\pi^2}{L^2} \\
& -c_1\frac{a_2 e^{i\omega t}\sin(\frac{n\pi x}{L})n^2\pi^2}{L^2} + c_1\frac{a_1 e^{i\omega t}\sin(\frac{n\pi x}{L})n^2\pi^2}{L^2}]
\end{aligned} \tag{6}
$$

Dividing equations (5) and (6) by the expression $e^{i\omega t}\sin(\frac{n\pi x}{L})$ we have

$$
\begin{aligned}
& c_1(a_2 - a_1) = EI_1\frac{a_1 n^4\pi^4}{L^4} - \rho A_1 a_1\omega^2 + EA_1\theta T\frac{a_1 n^2\pi^2}{L^2} \\
& -(e_0 a)^2[\rho A_1\frac{a_1\omega^2 n^2\pi^2}{L^2} + EA_1\theta T\frac{a_1 n^4\pi^4}{L^4} + c_1\frac{a_2 n^2\pi^2}{L^2} - c_1\frac{a_1 n^2\pi^2}{L^2}]
\end{aligned} \tag{7}
$$

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$$
\begin{aligned}
&-k_1 a_2 - c_1(a_2 - a_1) = EI_2 \frac{a_2 n^4 \pi^4}{L^4} - \rho A_2 a_2 \omega^2 + EA_2 \theta T \frac{a_2 n^2 \pi^2}{L^2} \\
&-(e_0 a)^2 [\rho A_2 \frac{a_2 \omega^2 n^2 \pi^2}{L^2} + EA_2 \theta T \frac{a_2 n^4 \pi^4}{L^4} - k_1 \frac{a_2 n^2 \pi^2}{L^2} - c_1 \frac{a_2 n^2 \pi^2}{L^2} \\
&+ c_1 \frac{a_1 n^2 \pi^2}{L^2}]
\end{aligned} \tag{8}
$$

Simplifying equation (7) from the ρA_1 and equation (8) ρA_2 is obtained by

$$
\begin{aligned}
&EI_1 \frac{a_1 n^4 \pi^4}{\rho A_1 L^4} - a_1 \omega^2 + E\theta T \frac{a_1 n^2 \pi^2}{\rho L^2} - (e_0 a)^2 [\frac{a_1 \omega^2 n^2 \pi^2}{L^2} \\
&+ E\theta T \frac{a_1 n^4 \pi^4}{\rho L^4} + c_1 \frac{a_2 n^2 \pi^2}{\rho A_1 L^2} - c_1 \frac{a_1 n^2 \pi^2}{\rho A_1 L^2}] - \frac{c_1(a_2 - a_1)}{\rho A_1} = 0
\end{aligned} \tag{9}
$$

$$
\begin{aligned}
&EI_2 \frac{a_2 n^4 \pi^4}{\rho A_2 L^4} - a_2 \omega^2 + E\theta T \frac{a_2 n^2 \pi^2}{\rho L^2} \\
&-(e_0 a)^2 [\frac{a_2 \omega^2 n^2 \pi^2}{L^2} + E\theta T \frac{a_2 n^4 \pi^4}{\rho L^4} - k_1 \frac{a_2 n^2 \pi^2}{\rho A_2 L^2} - c_1 \frac{a_2 n^2 \pi^2}{\rho A_2 L^2} + c_1 \frac{a_1 n^2 \pi^2}{\rho A_2 L^2}] \\
&+ \frac{k_1 a_2}{\rho A_2} + \frac{c_1(a_2 - a_1)}{\rho A_2} = 0
\end{aligned} \tag{10}
$$

we ask $\lambda_n = \frac{n\pi}{L}$ and $G = 1 + (e_0 a)^2 \lambda_n^2$ have the replace in the equations (9) and (10)

$$
(EI_1 \frac{\lambda_n^4}{\rho A_1} - \omega^2 G - E\theta T \frac{\lambda_n^2 G}{\rho} + c_1 \frac{G}{\rho A_1}) a_1 - \frac{c_1 G}{\rho A_1} a_2 = 0 \tag{11}
$$

$$
(EI_2 \frac{\lambda_n^4}{\rho A_2} - \omega^2 G - E\theta T \frac{\lambda_n^2 G}{\rho} + \frac{k_1 G}{\rho A_2} + c_1 \frac{G}{\rho A_2}) a_2 - \frac{c_1 G}{\rho A_2} a_1 = 0 \tag{12}
$$

Calculate the determinant of this system of equations we have the expression (13)

$$
\begin{bmatrix}
(EI_1 \frac{\lambda_n^4}{\rho A_1} - \omega^2 G - E\theta T \frac{\lambda_n^2 G}{\rho} + c_1 \frac{G}{\rho A_1}) a_1 & -\frac{c_1 G}{\rho A_1} a_2 \\
-\frac{c_1 G}{\rho A_2} a_1 & (EI_2 \frac{\lambda_n^4}{\rho A_2} - \omega^2 G - E\theta T \frac{\lambda_n^2 G}{\rho} + \frac{k_1 G}{\rho A_2} c_1 \frac{G}{\rho A_2}) a_2
\end{bmatrix}
\begin{Bmatrix} a_1 \\ a_2 \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \end{Bmatrix} \tag{13}
$$

We obtain

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$$\omega^4 - (EI_1 \frac{\lambda_n^4}{G\rho A_1} - 2E\theta T \frac{\lambda_n^2}{\rho} + \frac{c_1}{\rho A_1} + \frac{c_1}{\rho A_2} + \frac{k_1}{\rho A_2} + EI_2 \frac{\lambda_n^4}{G\rho A_2})\omega^2 + \lambda_n^8 \frac{E^2 I_1 I_2}{G^2\rho^2 A_1 A_2}$$
$$- E^2\theta T\lambda_n^6 \frac{A_1 I_2 + A_2 I_1}{G\rho^2 A_1 A_2} + \lambda_n^4 \frac{E^2\theta^2 T^2 A_1 A_2}{\rho^2 A_1 A_2} + c_1\lambda_n^4 \frac{EI_2 + EI}{G\rho^2 A_1 A_2} - c_1 E\theta T\lambda_n^2 \frac{A_1 + A_2}{\rho^2 A_1 A_2} \tag{14}$$
$$+ (EI_1 \frac{\lambda_n^4}{G\rho^2 A_1 A_2} - E\theta T \frac{\lambda_n^2}{\rho^2 A_2} + \frac{c_1}{\rho^2 A_1 A_2})k_1 = 0$$

by posing

$$\alpha_n = E\frac{\lambda_n^4(A_1 I_2 + A_2 I_1)}{G\rho A_1 A_2} - 2E\theta T\frac{\lambda_n^2}{\rho} + \frac{c_1(A_1 + A_2) + k_1 A_1}{\rho A_1 A_2} \tag{15}$$

and

$$\beta_n = \lambda_n^8 \frac{E^2 I_1 I_2}{G^2\rho^2 A_1 A_2} - E^2\theta T\lambda_n^6 \frac{A_1 I_2 + A_2 I_1}{G\rho^2 A_1 A_2} + \lambda_n^4 \frac{E^2\theta^2 T^2 A_1 A_2}{\rho^2 A_1 A_2} + c_1\lambda_n^4 \frac{EI_2 + EI}{G\rho^2 A_1 A_2}$$
$$- c_1 E\theta T\lambda_n^2 \frac{A_1 + A_2}{\rho^2 A_1 A_2} + (EI_1 \frac{\lambda_n^4}{G\rho^2 A_1 A_2} - E\theta T\frac{\lambda_n^2}{\rho^2 A_2} + \frac{c_1}{\rho^2 A_1 A_2})k_1 \tag{16}$$

Equation (14) can be written

$$\omega^4 - \alpha_n\omega^2 + \beta_n = 0 \tag{17}$$

We note that the discriminant of the algebraic equation is Bisquare

$$\Delta = \alpha_n^2 - 4\beta_n \tag{18}$$

Thus equation (17) has two different real roots

$$\omega^2{}_{nI} = \frac{1}{2}(\alpha_n - \sqrt{\alpha_n^2 - 4\beta_n}) \tag{19}$$

$$\omega^2{}_{nII} = \frac{1}{2}(\alpha_n + \sqrt{\alpha_n^2 - 4\beta_n}) \tag{20}$$

For each of the resonant frequencies, the associated amplitude ratio of the vibration modes of the inner and outer tubes for DWNTs with the initial stress is given [8]

by $$\frac{a_1}{a_2} = \frac{(EI_2 \frac{\lambda_n^4}{\rho A_2} - \omega^2 G - E\theta T\frac{\lambda_n^2 G}{\rho} + \frac{k_1 G}{\rho A_2} + c_1 \frac{G}{\rho A_2})}{\frac{c_1 G}{\rho A_2}} \tag{21}$$

After simplification we obtain

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$$\frac{a_1}{a_2} = 1 + EI_2 \frac{\lambda_n^4}{c_1 G} - \frac{\omega^2 \rho A_2}{c_1} - E\theta T \frac{\lambda_n^2 A_2}{c_1} + \frac{k_1}{c_1} \quad (22)$$

To examine the influence of temperature change on the vibrations of the nanotubes type DWNT, we discuss the results including and excluding the thermal effect [9]. It follows that the reports of the results with the temperature change to those without temperature change are respectively given by

$$\chi_I = \frac{\omega_{nI}}{\overset{\circ}{\omega}_{nI}} \quad \text{and} \quad \chi_{II} = \frac{\omega_{nII}}{\overset{\circ}{\omega}_{nII}}\ ; \quad (23)$$

With ($\overset{\circ}{\omega}_{nI}$ et $\overset{\circ}{\omega}_{nII}$; we have $T = 0$)

The parameters used in the calculations for DWNTs are given as follows

E=1TPa $\rho = 2.3g\ cm^{-3}$ $k_1 = 0$ $d_1 = 0.7\,nm$ $d_2 = 1.4\ nm$

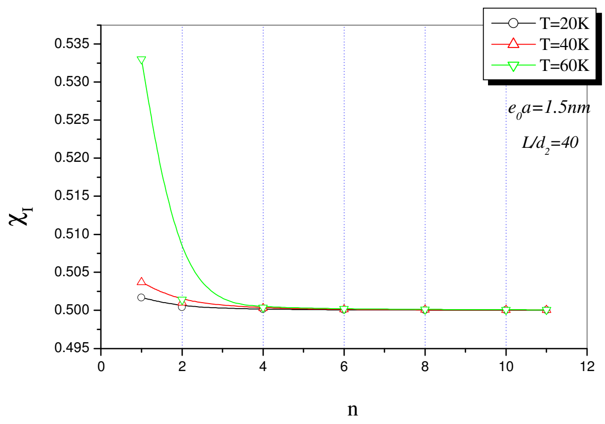

Figure 2: The thermal effect on the normal frequency ω_{nI} with lower elongation $\frac{L}{d_2} = 40$ in the case of low temperature.

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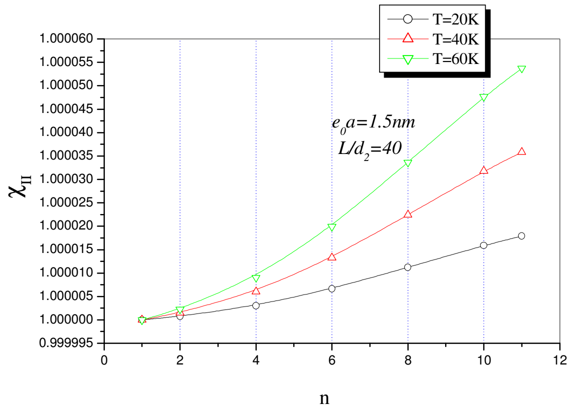

Figure 3: The thermal effect on the highest normal frequency ω_{nII} with the elongation $\frac{L}{d_2} = 40$ in the case of low temperature

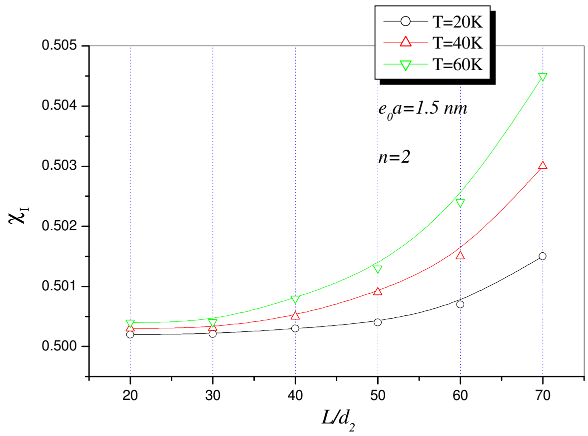

Figure 4: The thermal effects on the lower frequency ω_1 with the normal vibration mode n = 2 in the case of low temperature.

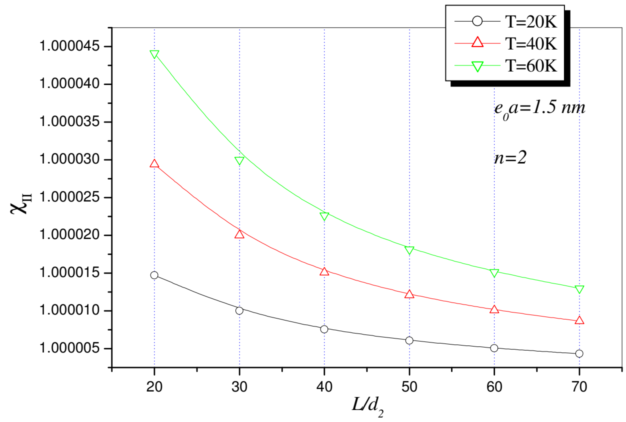

Figure 5: The thermal effects on the higher frequency ω_{nII} with the normal vibration mode n = 2 in the case of low temperature.

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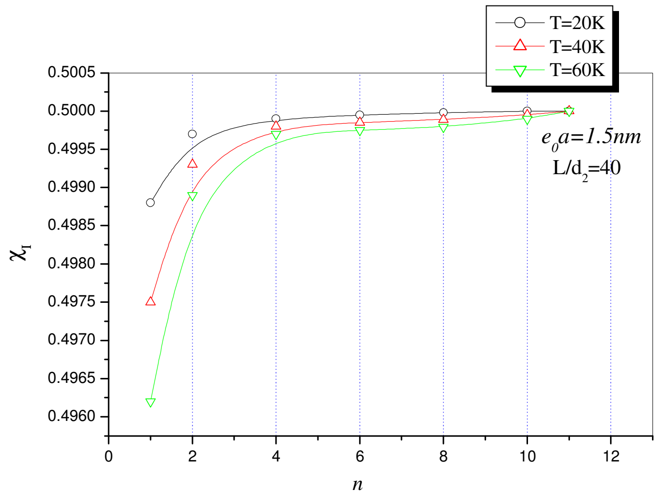

Figure 6: The thermal effect on the normal frequency ω_{nI} with lower elongation $\frac{L}{d_2} = 40$ in the case of high temperature.

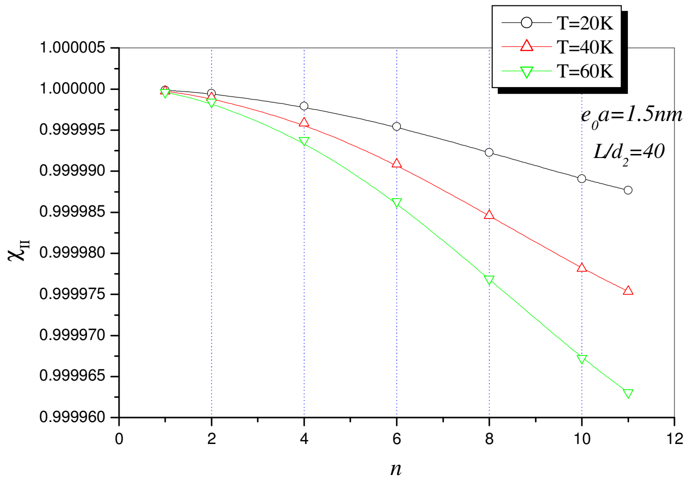

Figure 7: The thermal effect on the highest normal frequency ω_{nII} with the elongation $\frac{L}{d_2} = 40$ in the case of high-temperature

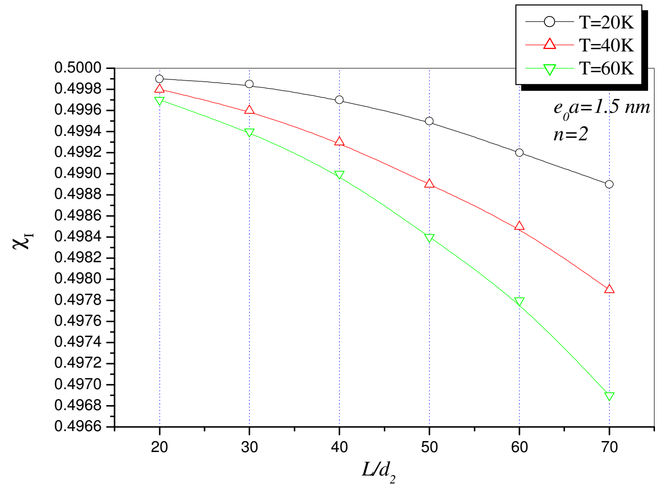

Figure 8: The thermal effects on the lower frequency ω_1 with the normal vibration mode n = 2 in the case of high temperature.

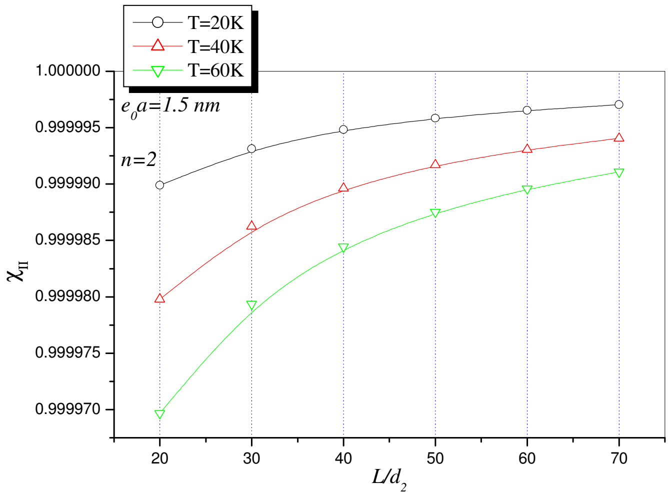

Figure 9: The thermal effects on the higher frequency ω_{nII} with the normal vibration mode n = 2 in the case of high-temperature

We note that the thermal expansion coefficients for the CNTs are negative for the case of low temperature, they become positive at elevated temperature. Accordingly, the values of the ratios χ_I and χ_{II} the above calculated for both low and high temperatures. For the case of low temperature, $\theta = -1.6 \times 10^{-6} K^{-1}$ it is assumed. With elongation $\frac{L}{d_2} = 40$, thermal effects on the lower and higher frequency normal normal frequency are shown in Figures (2) and (3), respectively. With the vibration mode n = 2, the thermal effects ω_{nI} and ω_{nII} represented by the ratios χ_I and χ_{II} are shown in Figures (4) and (5). The thermal effect on the normal frequency ω_{nI} is less significant while for the highest normal frequency ω_{nII} is insensitive to temperature change. The thermal effect on the lower normal frequency decreases with the increase of the number n and becomes more significant with the increase in

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the elongation $\frac{L}{d_2} = 40$ and temperature change T. Moreover, it can be observed in Figures (2; 4) that the values of ω_{nI} and ω_{nII} accounting for the thermal effect are larger than those that ignore the influence of temperature change. For the case of high temperature, $\theta = 1.1 \times 10^{-6} K^{-1}$ it is assumed with elongation $\frac{L}{d_2} = 40$, thermal effects on the lower and higher frequency normal normal frequency are obtained, which are illustrated in the figures (6) to (9). They can be found that the thermal effect on the normal frequency ω_{nI} is less significant while the influence of temperature change on the highest normal normal frequency ω_{nII} is very insignificant.This is consistent in case of low temperature [10]. Can be clearly seen in Figures (6, 7, 8, 9) that the values ω_{nI} and since ω_{nII} the thermal effect is smaller than those to the exclusion of the influence of temperature change, which is contrary to the case in the room or low temperature [11].

It is clear in Figures (10) to (13) that the influence of local non-effect on the values of ω_{nI} and ω_{nII} is smaller in the case of low temperature or there are several values which to coincide report χ_{II} [12]. In what follows, we discuss the sensitivity of the current model to the value of the parameter a, as shown in the figures (14) and (15). Shown in Figures (14) and (15) that the influence of the non-local effect on the transverse vibrations of carbon nontubes deviation (DWNTs) with a high elongation are not very sensitive to variation of a parameter value[13]. This implies that for a specific effect on the diameter of transverse vibration of DWNTs with the elongation is almost independent of its geometry[14].

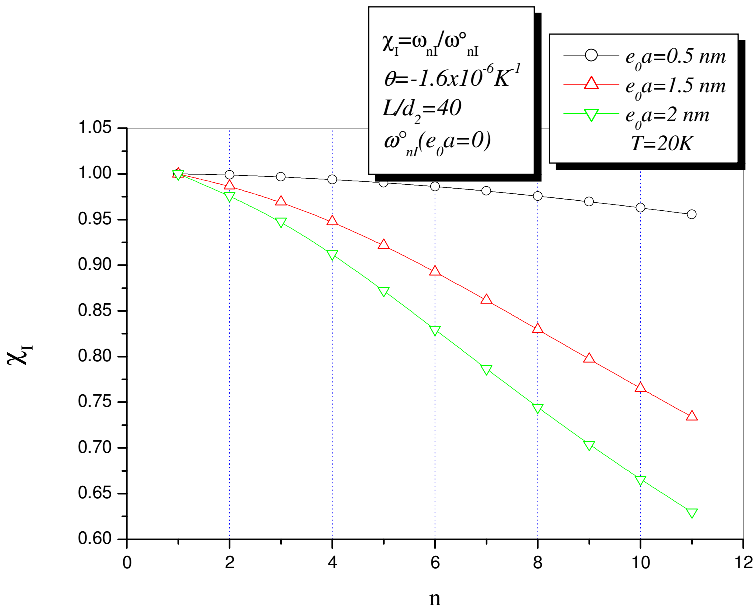

Figure 10: The influence of non local effect on the lower frequency normal ω_{nI} in the case of low temperature.

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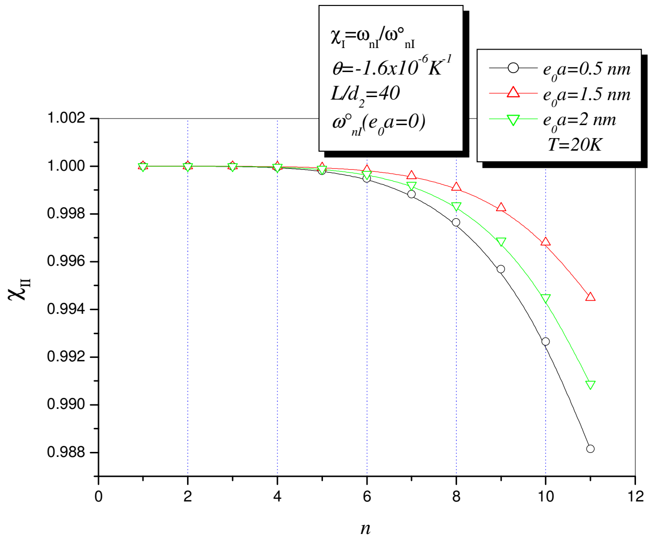

Figure 11: The influence of the non-local effect on the highest normal frequency ω_{nII} in the case of low temperature.

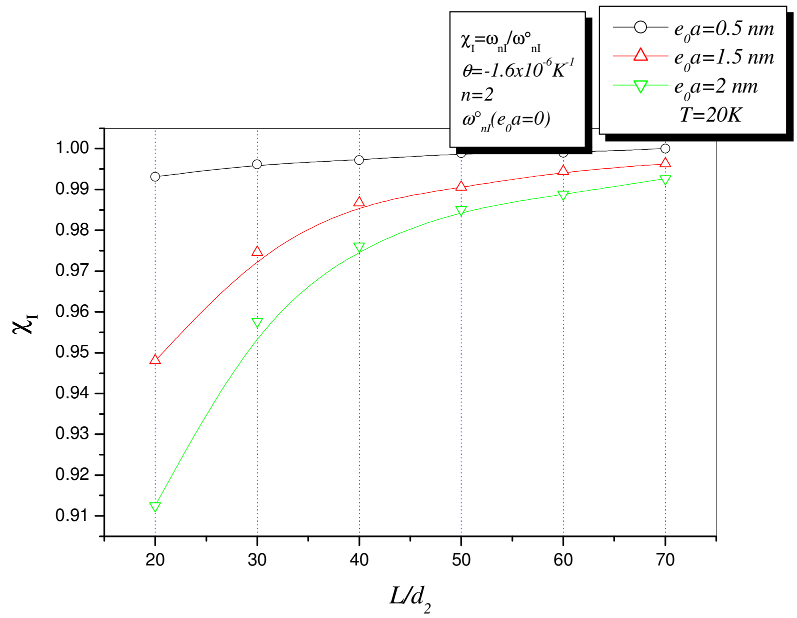

Figure 12: The influence of the non-local effect on the normal lower frequency vibration mode ω_1 with n = 2 in the case of low temperature.

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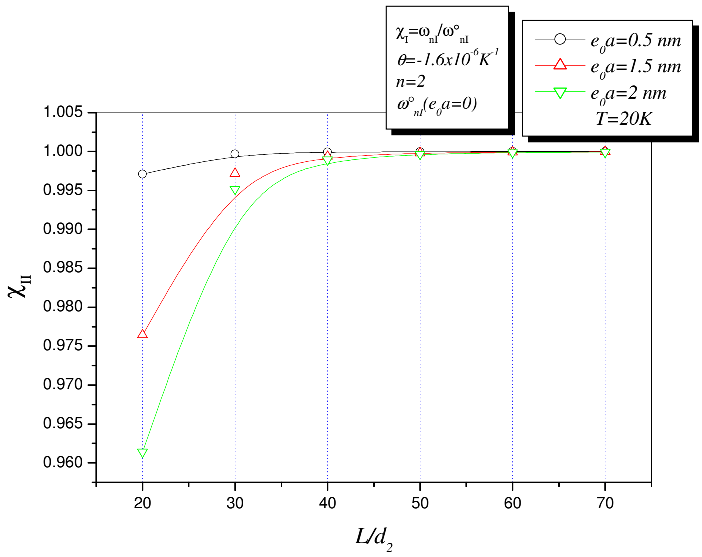

Figure 13: The influence of the non-local effect on the higher frequency ω_{nII} with the normal vibration mode n = 2 in the case of low temperature.

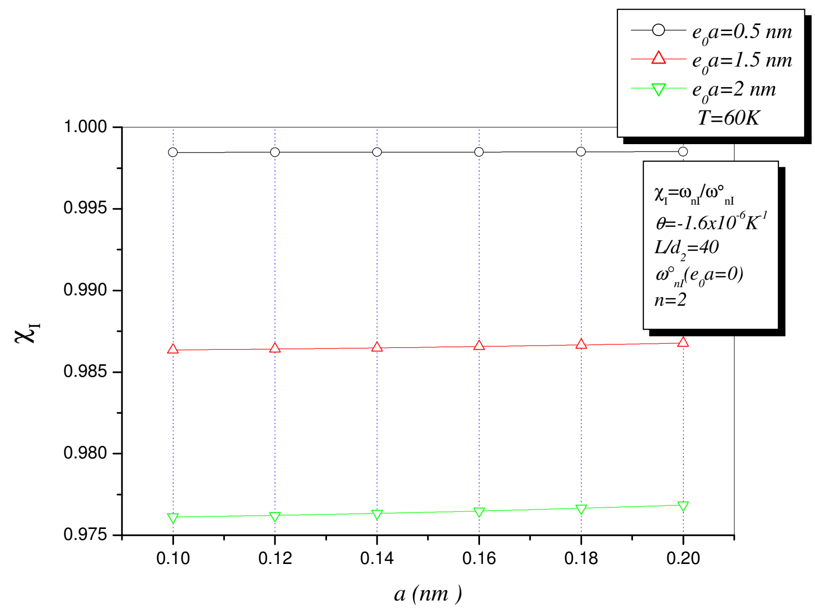

Figure 14: Ratio between the value of the parameter χ_I and a in the case of low temperature.

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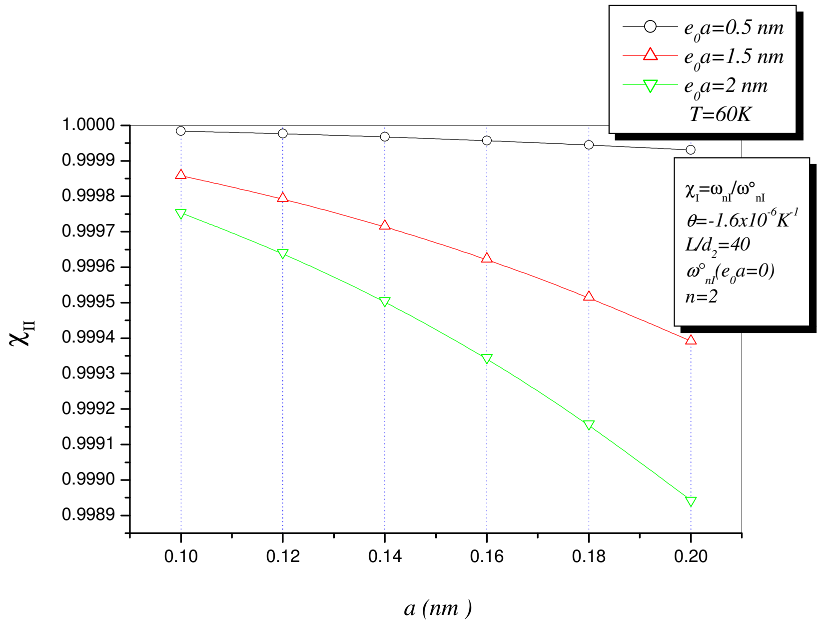

Figure 15: Ratio between the value of the parameter χ_{II} and a in the case of high temperature.

4.0 CONCLUSION

Based on the theory of Euler-Bernoulli beam, the general equation of transverse vibration of a resilient beam under the transverse pressure is made. Following this general equation, a double elastic beam model is developed for transverse vibrations of DWNTs, it takes into account the thermal effect. For the case of DWNT simply supported, the natural frequencies and reports associated with the amplitudes of the inside and outside of the tube are determined. We conclude that the thermal effect on the normal frequency ω_{n1} is less significant while the normal frequency ω_{n2} is high and relatively insensitive to temperature variation. We also find that the values of accounting ω_{n1} and ω_{n2} the thermal effect are larger than those that ignore the influence of the temperature change in the case of the part to low temperature. Consider that the values ω_{n1} and ω_{n2} with thermal effects are smaller than those where there is no temperature. Furthermore, we find that $\frac{a_1}{a_2}$ the amplitude ratio is independent of the temperature variation. We also show that for a specific diameter, the thermal effect on the transverse vibration of a DWNT with the elongation is almost independent of geometry.

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