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Instability and frequency sensitivity analysis of single-walled carbon nanotubes conveying fluid under thermomagnetic field considering the surface effect

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ABSTRACT: In this investigation according to the nonlocal nonlinear Euler-Bernoulli beam theory, the instability and frequency sensitivity analysis of single-walled carbon nanotube conveying fluid is studied. The thermomagnetic field, residual stress and surface elasticity, viscoelastic foundation and small-scale effects on the governing equation of single-walled carbon nanotube are taken into account. The Galerkin decomposition method with the trigonometric shape functions corresponding to the standard boundary conditions including simple-simple, clamped-simple and clamped-clamped at two ends of carbon nanotube are employed to solve. The eigenvalues and critical fluid velocity in the threshold of instability of system are computed by extracting the mass, stiffness and damping matrices. The magnetic intensity, change of temperature in the cases of high and low-temperature conditions, length of nanotube, outer diameter of nanotube and small scale parameters are conceded as the input factors for sensitivity analysis. The qualitative and quantitative effects of input factors on the critical fluid velocity and natural frequencies of single-walled carbon nanotube are computed and compared with together by normalization. The results of sensitivity analysis of present work can be used for optimal or target design of single-walled carbon nanotube for different applications especially for drug delivery to kill metastatic cancer cells.

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1- Introduction

Carbon NanoTubes (CNTs) can be used for biological applications such as drug delivery nanotubes to kill the metastatic cancer cells due to their excellent physical properties, small size, and hollow geometry. Selective delivery of anticancer drugs, called targeted therapies, will dramatically improve cancer treatment by using carbon nanotubes as an ideal carrier for drug delivery systems. Anticancer drugs can be delivered to cancer cells or tissues using magnetic field-guided nanotubes. Due to the high sensitivity of the drug delivery process, the analysis of dynamic stability and vibrational response of carbon nanotubes carrying fluid under a magnetic field is of great importance and has been considered by scientists. There is a lot of research on the dynamic instability and vibration analysis of carbon nanotubes using various theories.

Ru et al. [1] used the classical Euler-Elastic beam theory to investigate the effects of the elastic medium on the vibrational frequencies and the instability of the carbon nanotubes conveying fluid. Using the non-local Euler-Bernoulli beam classical beam theory, Li and Chang [2] investigate the effects of nonlocal parameters, fluid viscosity, aspect ratio and elastic bed coefficient on the free vibration of non-local fluid viscosity of carbon nanotubes conveying fluid under the elastic medium. Using the Knudsen number and slip boundary condition, Kaviani and Mirdamadi [3] proposed a model for fluid-structure interaction problems in a nanotube. Wang [4] employed the Euler–Bernoulli beam model to investigate the critical velocity and natural frequency of single-walled CNT conveying fluid by considering the surface effect. The flutter instability and free vibration and in CNTs conveying fluid considering the effect of slip condition and nonlocal elasticity were studied by Bahaadini et al. [5]. The instability condition of single-walled CNT conveying fluid under the thermomagnetic field in the anticancer drug delivery process were studied by Sadeghi et al. [6]. Sedighi [7] by considering the velocity correction factor for different slip condition, investigated the instability condition of carbon and boron nitride nanotube under thermomagnetic field based on the Euler–Bernoulli beam model.

In this study, considering the effects of thermomagnetic filed and the theory of surface elasticity with the nonlocal Euler–Bernoulli beam theory, the natural frequency and critical velocity of single-walled CNT conveying fluid are computed. The magnetic intensity, change of temperature, length of nanotube and small scale parameters are selected as factors to investigate the sensitivity analysis of SWCNT conveying fluid. The low and high temperature conditions are considered to apply the change of temperature.

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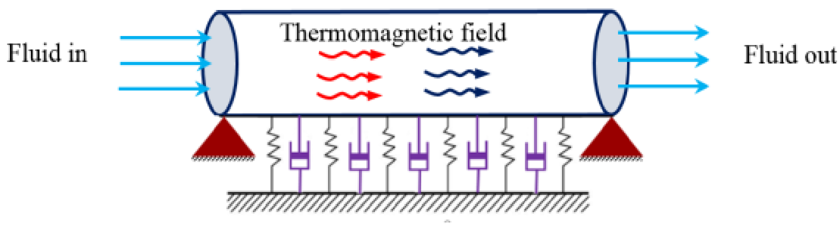

Fig. 1. Schematic of single-walled CNT conveying fluid

2- Methodology

Fig. 1 shows a single-walled CNT conveying fluid subjected to the thermomagnetic field under the viscoelastic foundation.

Based on the nonlocal Euler–Bernoulli beam theory considering the small scale effect, the governing equation of nonlocal SWCNT conveying magnetic fluid under viscoelastic foundation by applying the surface effect and velocity correction factor subjected to the thermomagnetic axial field can be presented as follows;

$$
\begin{aligned}
&EI^*\frac{\partial^4 w(x,t)}{\partial x^4}+(m_f+m_c)\frac{\partial^2 w(x,t)}{\partial t^2}+m_f v^2\frac{\partial^2 w(x,t)}{\partial x^2}\\
&+2m_f v\frac{\partial^2 w(x,t)}{\partial x\,\partial t}+C_m\frac{\partial w(x,t)}{\partial t}+K_m w(x,t)\\
&-(e_0a)^2\left\{(m_f+m_c)\frac{\partial^4 w(x,t)}{\partial t^2\partial x^2}+m_f v^2\frac{\partial^4 w(x,t)}{\partial x^4}\right\}\\
&-(e_0a)^2\left\{2m_f v\frac{\partial^4 w(x,t)}{\partial x^3\partial t}+C_m\frac{\partial^3 w(x,t)}{\partial t\,\partial x^2}+K_m\frac{\partial^2 w(x,t)}{\partial x^2}\right\}=0
\end{aligned}
\tag{1}
$$

where, e_0a stands for the nonlocal parameter on the mechanical properties of nanostructures and EI^* is the effective bending stiffness by applying the surface effect can be formulated as follows;

$$
EI^*=\frac{\pi E\left(d_{out}^4-d_{in}^4\right)}{64}+\frac{\pi E_s\left(d_{out}^3+d_{in}^3\right)}{8}
\tag{2}
$$

Table 1. Trigonometric shape functions for different boundary conditions of single-walled CNT conveying fluid

Boundary conditions	Shape functions
S-S	$\Gamma(\tau.\xi)=\sum_{i=1}^{N}A_i(\tau)\sin(i\pi\xi)$
C-C	$\Gamma(\tau.\xi)=\sum_{i=1}^{N}A_i(\tau)\sin(\pi\xi)\sin(i\pi\xi)$
C-S	$\Gamma(\tau.\xi)=\sum_{i=1}^{N}A_i(\tau)\sin\left(\frac{\pi\xi}{2}\right)\sin(i\pi\xi)$

Eq. (1) can be rewritten as follows; By introducing the following dimensionless parameters and variable as following;

$$
\begin{aligned}
&\Gamma(x,t)=\frac{w(x,t)}{L},\xi=\frac{x}{L},\tau=\frac{t}{L^2}\sqrt{\frac{EI^*}{m_f+m_c}},v=VL\sqrt{\frac{m_f}{EI^*}},\mu=\left(\frac{e_0a}{L}\right)^2\\
&\alpha_c=C_m\frac{L^2}{\sqrt{EI^*(m_f+m_c)}},\alpha_K=K_m\frac{L^4}{EI^*}\\
&\alpha_F=-\frac{EA}{1-2\upsilon}\alpha_X\Delta T+2\tau_s(d_{in}+d_{out})+\frac{1}{\eta}B_0^2A
\end{aligned}
$$

Eq. (1) can be rewritten as follows;

$$
\begin{aligned}
&\frac{\partial^4\Gamma}{\partial\xi^4}+\frac{\partial^2\Gamma}{\partial\tau^2}+v^2\frac{\partial^2\Gamma}{\partial\xi^2}+2v\sqrt{\beta}\frac{\partial^2\Gamma}{\partial\xi\partial\tau}+\alpha_c\frac{\partial\Gamma}{\partial\tau}+\alpha_K\Gamma+\alpha_F\frac{\partial^2\Gamma}{\partial\xi^2}\\
&-\mu\left\{\frac{\partial^2\Gamma}{\partial\tau^2\partial\xi^2}+v^2\frac{\partial^4\Gamma}{\partial\xi^4}+2v\sqrt{\beta}\frac{\partial^4\Gamma}{\partial\tau\partial\xi^3}+\alpha_c\frac{\partial\Gamma}{\partial\tau\partial\xi^2}+\alpha_K\frac{\partial^2\Gamma}{\partial\xi^2}\right\}\\
&-\mu\left\{\alpha_F\frac{\partial^4\Gamma}{\partial\xi^4}\right\}=0
\end{aligned}
\tag{3}
$$

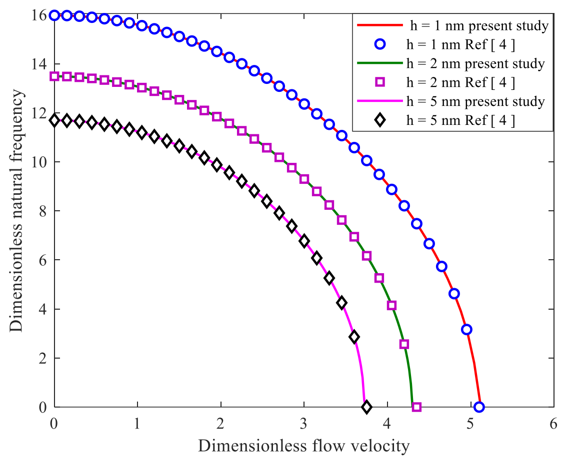

Fig. 2. Comparison and verification of present work with [4] for aspect ratio of 10

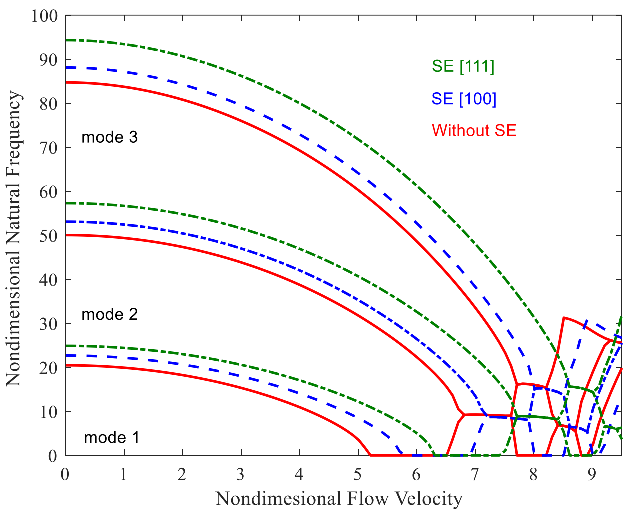

Fig. 3. The surface effect on the non-dimensional frequency at mode 1 to 3 of single-walled CNT conveying fluid with C-C boundary condition

The Galerkin decomposition approximation method along with the admissible trigonometric shape functions for different standard boundary conditions including S-S, C-S and C-C, as shown in Table 1, are used to solve the Eq. (3).

3- Discussion and Results

The geometrical properties of single-walled CNT are the outer diameter $d_{out} = 7\text{nm}$, the layer's thickness , and the length of CNT $L = 20d_{out}$. Moreover, the mechanical properties of SWCNT are Young's modulus $E = 1\text{Tpa}$, the mass density $\rho = 1300\text{kg/m}^3$, the Poisson's ratio $\upsilon = 0.3$ and the fluid density $\rho = 1000\text{kg/m}^3$. As depicted in Fig. 2, the verification of the present work for the non-dimensional natural frequency of SWCNT conveying fluid are compared with obtained results in [4].

Fig. 3 illustrates the effect of surface elasticity on the critical flow velocity C-C at two ends of single-walled CNT. The values of magnetic intensity of the longitudinal magnetic field, change of temperature in the case of high temperature and Knudsen number are specified as $B_0 = 20\text{T}$, $\Delta T = 30\text{K}$. It can be seen from Fig. 3 that the predicted natural frequencies at three lowest modes and critical flow velocity of SWCNT by considering the surface in the cases of [111] and [100] are higher than without of surface effect. In another word, increasing of stiffness of single-walled CNT due to the surface effect, increases the natural frequencies and critical flow velocity of system for different boundary conditions.

4- Conclusions

The surface effect has a positive sensitivity on the natural frequency of single-walled CNT conveying fluid at modes 1 to 3 for different boundary conditions. The instability threshold of single-walled CNT conveying fluid can be postponed by consideration of surface effect. That means that the stiffness of system is increased by applying the surface effect. The magnetic intensity of the longitudinal magnetic field has a nonlinear positive effect on the flow critical fluid velocity and natural frequencies of CNT.

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