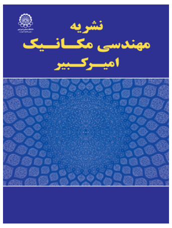

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The Effect of Magnetic Field and Fluid on the Primary and Secondary Frequency Response of Fluid-Conveying Carbon Nanotubes Using a Stress-Driven Nonlocal Integral Model

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ABSTRACT: In this article, the nonlinear forced vibrations of carbon nanotubes conveying magnetic nanofluid under a longitudinal magnetic field have been investigated. Using Von Karman's nonlinear strain field and the Euler-Bernoulli beam theory, the equations governing the nonlinear vibrations of carbon nanotubes are extracted. Using the method of multiple scales, the frequency response in primary resonance, superharmonic resonance, and subharmonic resonance is obtained. In order to consider the effects of small size, a stress-driven non-local integral model has been used. In the end, the effect of magnetic fluid and magnetic field intensity on frequency response and force response has been investigated. From the results, it can be seen that the presence of a magnetic field causes the system's vibration amplitude to be unstable and have a limited cycle. In this condition, the vibration response is quasi-periodic. However, the presence of magnetic fluid causes the vibration amplitude to be stable and the time response to alternate; In such a way that the Poincaré diagram shows a point in the phase plane. In the primary resonance, with the presence of the longitudinal magnetic field, as the excitation amplitude increases, the frequency response curves include two sub-amplitudes. One is an asymptotic curve with a horizontal axis and the other is a closed curve.

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1- Introduction

In recent years, multi-walled carbon nanotubes conveying ferromagnetic fluid have become a promising research path. Such materials may have diverse applications, from the implementation of filled tubes in magnetic force microscopy sensors [1] or as an array of high-density magnetic nanocores for future magnetic data storage devices [2] or so-called nano Containers in human medicine [3]. One of the most important issues in the treatment of acute cancerous diseases and tumors is to deliver the drug to the site of the disease and tumor in a sufficient amount without side effects on the adjacent healthy tissues. It took the drug movement [4, 5], especially iron-filled carbon nanotubes, which are new and potentially attractive tools for new anti-cancer therapeutic strategies.

All the results of the mentioned article are for two cases with and without the effect of the fluid and magnetic field in a wide range of magnetic field intensity.

2- Methodology

Fig. 1 shows a carbon nanotube conveying magnetic fluid under a longitudinal magnetic field located on an elastic foundation.

The equation of forced vibrations of nanobeam based on Stress-Driven non-local integral Model theory is as follows [6]:

$$EI\left[\frac{\partial^4 w}{\partial x^4}-l_s^2\frac{\partial^6 w}{\partial x^6}\right]-EA\left[\frac{3}{2}\frac{\partial^2 w}{\partial x^2}\left(\frac{\partial w}{\partial x}\right)^2-l_s^2\left[\left(\frac{\partial^2 w}{\partial x^2}\right)^2+4\frac{\partial w}{\partial x}\frac{\partial^2 w}{\partial x^2}\frac{\partial^3 w}{\partial x^3}+\frac{\partial^4 w}{\partial x^4}\left(\frac{\partial w}{\partial x}\right)^2\right]\right] \qquad (1)$$
$$+\rho A\frac{\partial^2 w}{\partial t^2}=P(x,t)$$

where *P(x,t)* is the sum of external harmonic loading, elastic foundation, the force caused by magnetic fluid flow, and force caused by the longitudinal magnetic field is defined. Using the Galerkin method, the partial differential equation can be converted to the following ordinary differential equation.

$$\ddot{q}+\gamma_1 q+\gamma_2\dot{q}+\gamma_3 q^3=f\ \operatorname{Cos}(\Omega t) \qquad (2)$$

There are different methods to solve the nonlinear equation number 2. The frequency response of this equation in primary and secondary resonance using the method of multiple scales is as follows:

$$\gamma_2+\left[\sigma_1-\frac{3}{8}.\frac{\gamma_3 a^2}{\sqrt{\gamma_1}}\right]=\left(\frac{f_1}{2a\sqrt{\gamma_1}}\right)^2\ ,\quad \textbf{Primary} \qquad (3)$$

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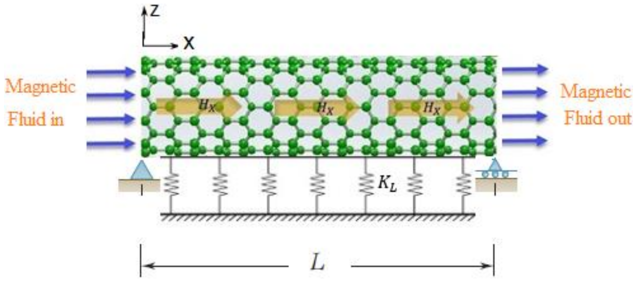

Fig. 1. Carbon nanotube conveying magnetic fluid under a longitudinal magnetic field

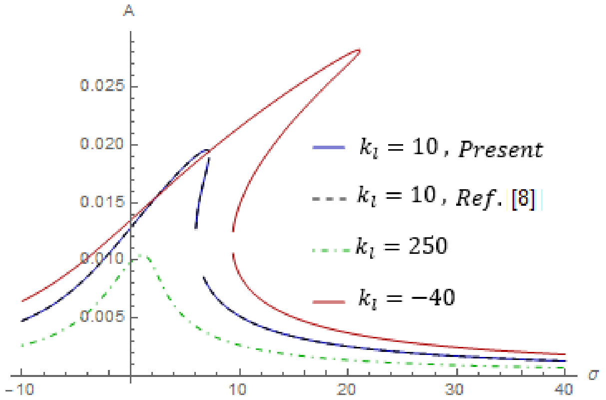

Fig. 2. Comparing the results of the frequency response in the primary resonance for a carbon nanotube conveying a magnetic fluid located on an elastic foundation with Ref. [8] $(H_x = 2*10^4, l_s = 0.01, V_f = 1)$

$$\gamma_2 + \left[\sigma_1 - \frac{3}{8}.\frac{\gamma_3 a^2}{\sqrt{\gamma_1}} -- \frac{3a_3\Lambda^2}{\sqrt{\gamma_1}}\right]^2 = (\frac{a_3\Lambda^3}{a\sqrt{\gamma_1}})^2, \qquad (4)$$

Supperharmonic resonance

$$(3\gamma_2)^2 + \left[\sigma_1 - \frac{9\gamma_3\Lambda^2}{\sqrt{\gamma_1}} - \frac{9}{8}\frac{\gamma_3 a^2}{\sqrt{\gamma_1}}\right]^2 = (\frac{9\gamma_3\Lambda a}{4\sqrt{\gamma_1}})^2, \qquad (5)$$

Subharmonic resonance

where a, σ_1 and $\Lambda = f_1/(2(\alpha_1 - \Omega^2))$ are, respectively: response range, parameter deviation, and dimensionless excitation range.

3- Results and Discussion

In order to investigate the structure-fluid interaction of a carbon nanotube conveying a magnetic nanofluid located in a longitudinal magnetic field, the parameters are considered as in Ref. [8].

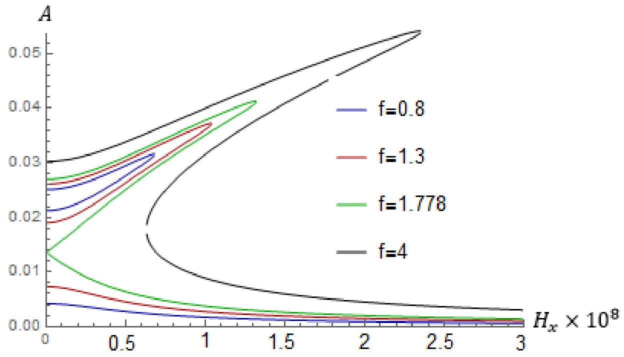

Fig. 3. Variations of the response amplitude in the initial resonance according to variations of the magnetic field intensity of different excitation amplitudes for a carbon nanotube located in a longitudinal magnetic field $(V_f = 1, l_s = 0.01)$

First, in order to ensure the correctness of the relations and results, the frequency response in the initial resonance for a carbon nanotube located on the elastic foundation in Fig. 2 is compared with the reference results [8]. As can be seen, the results are in good agreement. On the other hand, it can be easily seen that with the increase of the foundation coefficient, the response curve tends to the right, which indicates the non-linear behavior and greater hardening of the carbon nanotube. On the other hand, when the foundation coefficient becomes negative, the curve tilts to the left and shows a linear behavior, the undesirable phenomenon of jumping is eliminated and the system becomes more stable.

The effect of the force excitation amplitude on the response amplitude with the change of H_x in the primary resonance with the presence of the longitudinal magnetic field is shown in Fig. 3. As can be seen, with the increase of the excitation range, the frequency response curves include two sub-ranges. The first domain includes an asymptotic curve with a horizontal axis, which reaches zero with increasing H_x of domain response. The second domain consists of a closed curve that expands as the excitation amplitude (f) increases. For a critical value of f , two branches are connected and a curve is obtained. The critical value of the excitation amplitude in the initial resonance is $f = 1.778$. As shown in Fig. 2, as the excitation amplitude increases, the amplitude response appears as a single-valued function of the longitudinal magnetic field.

4- Conclusion

In this article, the forced nonlinear vibrations of fluid-conveying carbon nanotubes located on elastic foundations under uniform distributed load were investigated. The carbon nanotube is under the longitudinal magnetic field and carries the magnetic nanofluid. The summary of the results obtained from this research is as follows:

The effect of the magnetic field increases the hardening effect and increases the non-linear behavior and consequently the instability of the system. On the other hand, the effect of the magnetic fluid causes the frequency response curves to be closed and the system to become more stable, and the amplitude of the undesirable phenomenon of jumping is reduced.

In the primary resonance, with the presence of a longitudinal magnetic field, with the increase of the excitation amplitude, the frequency response curves include two sub-amplitudes. One is an asymptotic curve with a horizontal axis and the other is a closed curve.

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