Nonlinear Vibrations of Graphene Reinforced Pipes Conveying Fluid

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Abstract

In this study, nonlinear vibrations of simply-supported pipes conveying fluid made of multilayer graphene reinforced composite materials have been investigated analytically and based on the Euler-Bernoulli beam theory. The constituent layers of the pipe wall thickness are considered to be made of polymer and graphene platelets and the reinforcing graphene platelets are varied by layers in the pipe wall thickness direction. Four different patterns for distribution of reinforcing graphene platelets, large deformations and Von-Karman nonlinear strain field are considered. The nonlinear governing equations are derived by Hamilton principle, they are converted to the ordinary differential equations by Galerkin method and then are solved analytically using the homotopy analysis method. The variations of the first nonlinear natural frequency of the system with respect to the variation of initial amplitude, fluid velocity, fluid density, pipe length and also time response of the nonlinear vibrations of the system are presented for different distribution patterns *V*, *X*, *O* and *U* of the graphene platelets. The results show that the first nonlinear natural frequency of the system for all distribution patterns of graphene platelets is decreased by increase of pipe length, fluid velocity and density but, increasing the initial amplitude increases the first nonlinear natural frequency and also the distribution pattern *V* has the highest nonlinear frequency comparing with the other distribution patterns.

Keywords

Pipes conveying fluid, Nonlinear vibrations, Homotopy analysis method, Functionally graded materials, Graphene platelets.

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1. Introduction

Fluid-structure interaction represents the interaction of the structures and fluid flow forces. Pipes conveying fluid are one of the most important structures which are studied in the field of fluid-structure interactions, they are used in different engineering applications such as gas and oil transportation lines, heat exchangers, nuclear reactors and pipes transfering fluid in boilers [1].

Linear and nonlinear vibration of pipes conveying fluid have been widely investigated in recent years. Paidoussis and Semler [2], studied the nonlinear dynamics of a fluid-conveying cantilevered pipe with an intermediate spring support. Post-buckling behavior and nonlinear vibration analysis of a fluid-conveying FGM pipe was investigated by Tang and Yang [3]. Nonlinear vibration and post-buckling of FG pipes conveying fluid by considering the rotary inertia and shear deformation effects was analytically studied by Khodabakhsh et al. [4].

Based on reviewed studies, nonlinear vibrations of pipes conveying fluid made of multilayer graphene reinforced composite materials have not been analytically investigated before and the effects of this new composite material on the nonlinear frequency and time response diagrams have not been specified. Therefore, in this study nonlinear vibrations of pipes conveying fluid made of multilayer composite material reinforced by graphene platelets based on the Euler-Bernoulli beam theory is investigated.

2. Graphene reinforced pipe conveying fluid model

The fluid conveying pipe in this study consists of several polymer layeres which are reinforced by graphene platelets as shown in figure 1.

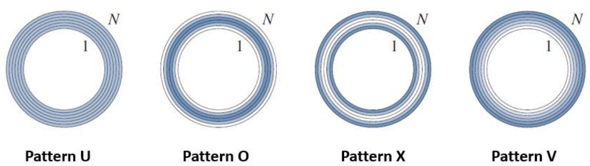

Figure 1: Four different distribution patterns of the graphene platelets along the thickness of the pipe

3. Governing equations

A simply-supported uniform polymer pipe conveying fluid reinforced by graphene platelets is considered as shown in figure 2.

Considering large deformation, Euler-Bernoulli beam theory and applying Von-Karman nonlinear strain field, the longitudinal strain component is introduced as [3]:

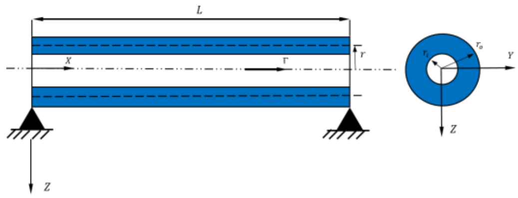

Figure 2: Simply-supported polymer pipe conveying fluid reinforced by graphene platelets

$$\varepsilon_{xx} = \frac{\partial u}{\partial x} - z\frac{\partial^2 w}{\partial x^2} + \frac{1}{2}\left(\frac{\partial w}{\partial x}\right)^2 \quad (1)$$

By assuming transverse vibration, limited stretching and using Hamilton's principle, the nonlinear governing equation of motion is obtained as:

$$\begin{aligned}&\left(m_f + m_p\right)\left(\frac{\partial^2 w}{\partial t^2}\right) + 2m_f\Gamma\frac{\partial^2 w}{\partial x\,\partial t}\\ &+m_f\Gamma^2\frac{\partial^2 w}{\partial x^2} + \left(EI\right)^*\frac{\partial^4 w}{\partial x^4} - P_0\left(\frac{\partial^2 w}{\partial x^2}\right)\\ &-\frac{\left(EA\right)^*}{2L}\left(\frac{\partial^2 w}{\partial x^2}\right)\int_0^L\left(\frac{\partial w}{\partial x}\right)^2 dx = 0\end{aligned} \quad (2)$$

4. Nonlinear vibration

Galerkin procedure is used to discretize the nonlinear equation of motion and then the closed-form expressions for the nonlinear frequency and time response of the vibration are obtained by using homotopy analysis method as below:

$$\omega_{nl} = \frac{1}{2}\left\{4\left[\frac{\left(EI\right)^*\left(\frac{\pi}{L}\right)^4 + \left(P_0 - m_f\Gamma^2\right)\left(\frac{\pi}{L}\right)^2}{m_p + m_f}\right] + 3a^2\left[\frac{\left(EA\right)^*\left(\frac{\pi}{L}\right)^4}{4\left(m_p + m_f\right)}\right]\right\}^{\frac{1}{2}} \quad (3)$$

$$\xi(t) = a\cos\left(\omega_{nl}t\right) + \frac{a^3}{32\omega_{nl}^2}\left(\cos\left(\omega_{nl}t\right) - \cos\left(3\omega_{nl}t\right)\right)\left[\frac{\left(EA\right)^*\left(\frac{\pi}{L}\right)^4}{4\left(m_p + m_f\right)}\right] \quad (4)$$

5. Results and Discussions

In order to validate the results of this study, a simply-supported pipe conveying fluid without reinforcing graphene platelets is considered and the time response of vibration is compared with those obtained by Tang and

Yang [3] in figure 3 and the results show a good agreement.

Table 1: Geometrical and physical properties of the pipe and conveying fluid

Parameter	Notation	Value
Length of the pipe	L	10m
Inner radius	r_i	0.08m
Outer radius	r_o	0.1m
Initial axial tension	P_0	-20N
Density of the fluid	ρ_f	$1000\frac{\text{kg}}{\text{m}^3}$
Fluid velocity	Γ	$100\frac{\text{m}}{\text{s}}$

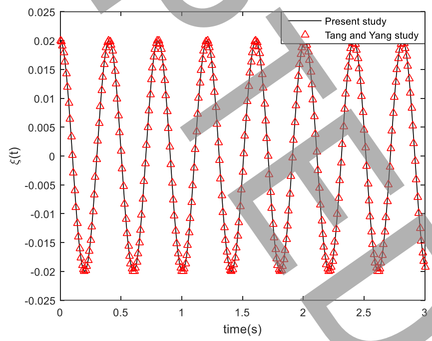

Figure 3: Comparison of the time response of vibration of pipe conveying fluid with the results of reference [3].

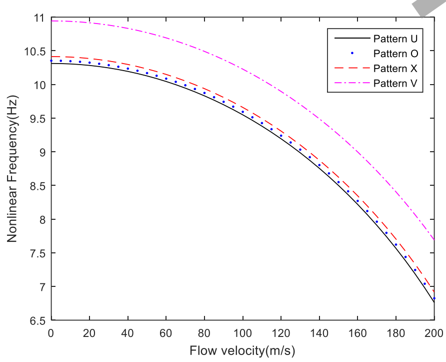

Figure 4: First nonlinear natural frequency of the graphene reinforced pipe conveying fluid in terms of the fluid velocity for the different graphene distribution patterns

The geometrical and physical properties of the graphene reinforced pipe conveying fluid are considered based on the Table 1.

The effects of increasing in the fluid velocity on the first nonlinear natural frequency is demonstrated in figure 4. As can be seen from figure 4, the first nonlinear natural frequency is decreased by the increase of the fluid velocity and pattern V predicts higher nonlinear frequencies in comparison with the other patterns.

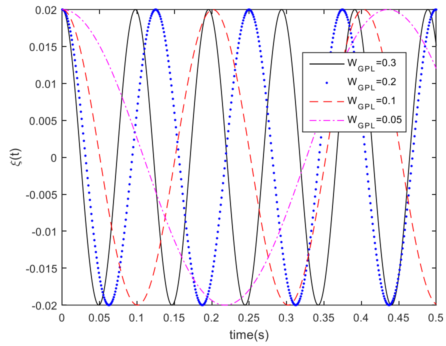

Figure 5: Comparison of the time response of the nonlinear vibration of pipe conveying fluid made of multilayer composite materials reinforced by graphene platelets for the different graphene weight fractions (pattern V).

Figure 5 illustrates that, increasing the weight fraction of the graphene increases the frequency of the vibration.

6. Conclusions

In this study, the analytical solution of nonlinear vibration of the pipes conveying fluid made of multilayer graphene reinforced composite materials have been investigated. Four different graphene distribution patterns are considered in the pipe wall thickness direction.

The results show that, increasing the length of the pipe, velocity and density of the fluid, decreases the first nonlinear natural frequency of the vibration for all graphene distribution patterns and also all distribution patterns predict approximately the same nonlinear frequencies when the length of the pipe is increasing.

Reference

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