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Research Article

A REVIEW ON VIBRATION OF FLUID-CONVEYING NANOTUBE THOROUGH A NONLOCAL STRAIN GRADIENT THEORY IN THERMAL ENVIRONMENT

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ABSTRACT:
Because of tremendous advances in science and engineering over the last few decades, there has never been a greater need to develop structures based on nanotechnology. Several scientists are interested in the dynamical behavior of nanotubes conveying fluid since they may be utilized in diverse nano-electromechanical systems such as the transfer of fluids and drug delivery. Past works on fluid-conveying nanotubes and dynamical characteristics of size-dependent vibration of fluid-conveying nanotubes are the subjects of the present review. Furthermore, prior research on fluid-conveying nanotube vibration under environmental conditions, particularly in the thermal environment, is being addressed.

Keywords: *Thermal environment, Nanotubes, Vibration, Fluid-conveying*

HIGHLIGHTS

- Considering the vibration of fluid-conveying nanotubes
- Investigating the size-dependent vibration behavior
- Addressing the vibration of fluid-conveying nanotube under thermal environment

1. INTRODUCTION

Nanotechnology has created a new area in materials, mechanical [1-5], and thermal engineering [6, 7], construction, chemistry, medical, electronic devices, biomaterials [8-11], and power production, leading to the next industrial revolution. Nanotubes (NTs) are a key component of modern nanostructures applications because of their unique mechanical, electrical, and physical capabilities. Carbon Nanotube (CNT) and Graphene Sheet are nanomaterials that show enormous potential in the development of new sensors, gas detection, and composite material and have inspired a great deal of interest in the industry. The excellent mechanical, electronic, and thermal characteristics of these nanomaterials enable their application in a wide range of possibilities, such as gas detection, solar panels, microbial identification, diagnosis systems, and composite material. Carbon Nanotube, an essential allotrope of carbon, is composed of Single-Walled CNTs (SWCNTs) or Multi-Walled CNTs (MWCNTs) [12, 13]. Carbon Nanotubes (CNTs) are carbon allotropes having cylindrical nanostructures, which are the first group of nano-products [14].

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CNT is a honeycomb-like structure formed of twisted graphite sheets. They are extraordinarily long and thin structures that are also robust, resistant, and adaptable [15]. If the CNT simply consists of a graphene pipe, it can be referred to as SWCNTs, and if it consists of many graphene rolled layers, it is referred to as MWCNTs [16]. Carbon nanotube exhibits remarkable mechanical, electrical, and magnetic properties, which allow for a wide range of utilization in Micro/Nano-electronic systems. Boron Nitride (BN) is a chemically resilient refractory combination composed of nitrogen and boron atoms, which provides it with unique features including a high elasticity modulus and great heat transfer [17, 18]. Boron Nitride Nanotubes (BNNTs) have superior piezoelectric characteristics to carbon nanotubes (CNTs), makes it a preferred choice for nanoelectromechanical systems (NEMS). Mechanical investigation of micro/nanoelectromechanical systems is a subject of research that has rapidly attracted a lot of attention. The study of the impacts of fluid-solid interactions on mechanical response, for instance, dynamic response, is crucial for developing the best fluid-conveying nanostructures. Carbon nanotubes and boron nitride nanotubes, for example, have a high elasticity modulus, excellent heat transfer, electrical conductivity, and other mechanical features. Because the influence of fluctuations of thermal on mechanical characteristics of the nanostructure is critical, the consideration of thermal vibration should be done on fluid-conveying CNTs.

The present review focuses on past efforts on fluid-conveying nanotubes and the dynamical features of size-dependent vibration of fluid-conveying nanotubes. Previous studies on fluid-conveying nanotube vibration under environmental conditions, notably in the thermal environment, are also being investigated.

2. Vibration of Fluid-conveying nanotubes

Mechanical investigation of Micro/Nanoelectromechanical systems is a field of study that has recently attracted a lot of interest [19-21]. There is strong contact between solid and liquid parts in several potential nanoelectromechanical systems (NEMS). Nanofluidics-based systems, for example, offer a wide range of utilization in several nanotechnology fields, including nano-medicine [22]. Considering the impact of fluid-solid interactions on mechanical response, such as dynamic response, is critical for an optimal design for fluid-conveying nanostructure because these nanostructures often work under applied loads. Carbon nanotubes and Boron Nitride nanotubes, for instance, have numerous outstanding properties, including a high elasticity modulus, strong heat transfer, and electrical conductivity, and other mechanical characteristics. Fluid flow within carbon nanotubes is an important and complex research area [23-25]. The impact of internal moving fluid on the total mechanical behavior of CNT, on the other hand, is a major concern. The main purpose of fluid mechanics of flow inside CNTs is to investigate how the wall-fluid interaction and fluid viscosity influence velocity distribution, as well as how the velocity distribution varies with pressure gradient in a non-classical approach [26]. Many scientists are interested in investigating the dynamical behaviors of fluid-conveying nanotubes [27] since they may be utilized in diverse nano-electromechanical systems such as fluid transfer and drug delivery [28]. They found that carbon nanotube is a tubular structure that can be utilized to transfer nano-flows after detecting them. Therefore, fluid-structure interactions might happen in fluid-conveying CNTs that may be examined similarly to macroscopic pipelines. For several decades, researchers have investigated fluid-conveying carbon nanotubes, and significant advancements have been accomplished. Wang [29] studied the impact of small length scales on double-walled carbon fluid-conveying nanotube. They concluded that the natural frequencies of double-walled carbon nanotubes conveying fluid were demonstrated to be dependent on the small length scale. The influence of small length scales on critical flow velocities, on the other hand, maybe ignored. Zhang et al. [30] investigated the impact of the surface effect on the propagation of terahertz waves in fluid conveying nanotubes. The flexural wave frequency rises as the flow velocity increases in the presence of surface effects. Lee and Chang [31] proposed a CNT embedded in an elastic medium and revealed that the nonlocal impact and influence of viscosity could modify the natural frequency of carbon nanotube. In their study, a SWCNT placed in an elastic medium with two fixed ends for conveying viscous fluid that is considered as a hollow cylindrical tube. Figure 1 depicts the dimensionless fundamental frequency of the SWCNT with different non-local parameters as a function of dimensionless flow velocity [31]. Lee and Chang [31] found that the fundamental frequency equals zero when the flow velocity increases to approximately 6.4.

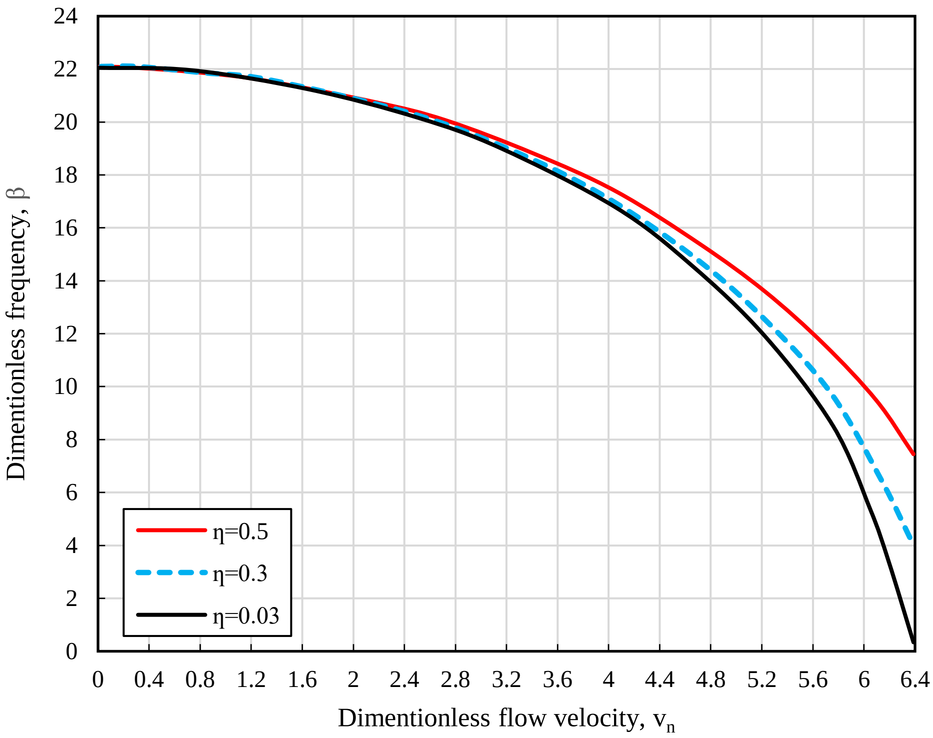

Fig. 1. Dimensionless fundamental frequency in terms of dimensionless flow velocity.

Mirramezani and Mirdamadi [32] investigated the influence of the Knudsen number on the fluid-conveying CNTs in terms of inner flow size. Furthermore, Zeighampour et al. [33] examined the effects of slip boundary conditions on double-walled CNTs, and they revealed that increasing the Knudsen number reduced the stability of the double-walled fluid-conveying CNT. Furthermore, Arani et al. [34] investigated the impacts of aspect ratios, Knudson number, and van der Waals forces on the evaluation of the stability of a double-walled boron nitride nanotube conveying fluid by using a nonlocal Timoshenko beam theory. They found that considering fluid with a higher Knudsen number led to shift the dynamic instability region to the lower frequency zone. Yan et al. [35] investigated the stability of triple-walled CNTs conveying fluid. They calculated the frequency of the beam and studied the effects of internal flow and van der Waals forces on the stability of carbon nanotubes. They revealed that the internal moving fluid plays a major role in the instability of triple-walled carbon nanotubes.

To analyze micro/nanostructures, theories of continuum mechanics such as classical and size-dependent theories can be applied. Because classical theory does not account for submicron structural discontinuity, it is incapable to capture size-dependent impact as the scale shifts to micro or nano [36]. Size-dependent approaches, such as non-local [37, 38], strain gradient [39], and couple stress [40], are preferable solutions and can provide more accurate results in these situations. It should be noticed that the aforementioned theories contain parameters of size-dependent, the values of precise of which must be validated by experimental data [41] analytical [42, 43], or simulated results [44]. The fabrication of material for conducting simulation or experimental analysis is a simple procedure for basic structures including graphene sheets or carbon nanotubes, but for composite structures, the procedure becomes difficult, forcing scientists to approximate the models using mathematics and hypotheses. Many studies have used nonlocal elasticity theory for analyzing features of size-dependent vibration of fluid-conveying nanotubes [45-47]. The non-local elasticity hypothesis assumes that the stress state at a particular point is a stress state's function at all other points in the body. Hence, the theory considers the impact of small length scales of nanomaterials. Askes and Aifantis [48] have proved that the nonlocal elasticity theory is essentially a stress gradient elasticity theory that can be employed to address static problems. However, in the case of dynamic study of carbon nanotube conveying-fluid, nonlocal beam and shell models may be insufficient options for evaluating such systems dynamic response. Some articles have been published on the use of strain gradient theory for dynamic investigations of nanotubes [49-52]. Wang [53] used strain gradient elasticity theory to examine the vibration behavior of fluid-carrying nanotubes. Kaviani and Mirdamad [54] analyzed wave propagation in CNTs conveying fluid using continuum mechanics size-dependent strain/inertia gradient theory. In comparison to carbon nanotubes, the literature on the dynamics of BN nanotubes conveying fluid is few. In this regard, it can mention the research done by Arani et al. [55], who considered the nonlinear vibration and instability of double-walled BN nanotubes using the modified couple stress theories. In addition, Ansari et al. [56] investigated the size-dependent non-linear free vibration and instabilities of fluid-conveying single-walled boron nitride nanotube (SWBNNT) by using a higher-order continuum model based on the modified strain gradient elastic theories. The size impact was captured using the modified strain gradient theory. To examine the nonlinear influence, geometric non-linearity was introduced to generate non-linear governing equations of motion. In their study, the system under examination is SWBNNT modeled as a Timoshenko beam with length L, thickness h, inner radius r_1, outer radius r_2, that is fluid-conveying and set in a viscoelastic medium [56]. The linear visco-Pasternak foundation model was adapted for simulating the viscoelastic medium. They determined that as the length scale parameter is big, it has a significant impact on the fluctuation of natural frequency. As a result, the classical continuum model is insufficient to forecast the behavior of nonlinear vibration, and a higher-order continuum model is required to lower the relative inaccuracy. By considering recent works, it was found that more study is required to investigate the most outstanding approaches to tackle the dynamic and static issues of boron nitride nanotubes conveying fluid in their practical application.

3. THERMAL ENVIRONMENT

CNTs have been utilized in gas storage, fluid conveying, and drug delivery due to their excellent mechanical, thermal, and electrical characteristics [57, 58]. Thermal vibration analysis should be performed on fluid-conveying CNTs due to the impact of thermal fluctuations on the mechanical characteristics of nanostructures is required significantly [59]. Multi-wall carbon nanotube (MWCNT) has a wide range of potential applications, including water-proof and tear-resistant cloth fabrics and concrete based on strength, electrical circuits based on electrical conductivity, sensors based on thermal conductivity, and even as a drug delivery vessel [60]. In the study of Malikan et al. [60], the damped vibration of SWCNTs is investigated in this work utilizing a novel shear deformation beam theory. The SWCNT is treated as a flexible beam placed in a viscoelastic foundation and subjected to a transverse dynamic load. The impact of nonlocal parameters, half-wavelength, damper, temperature, and material changes on the dynamic vibration of NTs are thoroughly examined in their research. They observed that modifying the heat in the environment raised the difference between outcomes of higher and lower-order non-local situations dramatically. The difference exhibited a rising trend, demonstrating the significance of using higher-order nonlocal strain gradient cases at high temperatures. As a result, at smaller deflection values, there may be no need to adopt the higher-order nonlocal strain gradient theories [60]. Sedighi et al. [61] simultaneously considered the impacts of length ratio, size dependence, magnetic field, and temperature environment on the nonlinear vibrational properties of composite nanotubes. They assumed that the entire system is subjected to an axial magnetic field as well as a thermal environment. They demonstrated that the configurations of the non-linear mode forms are substantially influenced by the high-temperature environment. In the study of Zhang et al. [59], a nonlocal elastic model is utilized to analyze the thermal vibration of a fluid-conveying Single-walled CNT. They concluded that the Root Mean Squared (RMS) amplitude of thermal vibration of Single-walled CNT conveying fluid anticipated by quantum theory is lower than that anticipated by the law of energy equipartition. Furthermore, Sedighi et al. [62] investigated the impacts of magneto-thermal field, and size-dependence on divergence velocity, and mode shapes of fluid-conveying NTs. It can be concluded that any increase in temperature raises the divergence velocity in a low-temperature media, but any increase in temperature decreases the critical velocity in a high-temperature media.

Xu et al. [63] analyzed hygro-thermo-magnetically induced vibrations of small-scale viscoelastic tubes containing flow with a spin motion under gravity and tangential loads by including surface effects. The impacts of hygro-thermo-magnetic loadings on the Euler-Bernoulli nanoscale tube's vibration frequencies are demonstrated in Fig. 2 [63]. Since raising the temperature generates initial internal stresses and strains in the nanotube, the temperature rise has a softening impact on the structure and causes a decrement in the thermo-elastic properties. Therefore, increasing the temperature reduces the system's vibration frequencies and divergence flow velocity. Their results showed that imposing hygro-thermal conditions has a negative influence on the system's bending rigidity and a lowering impact on the vibration frequencies of the small-scale tube.

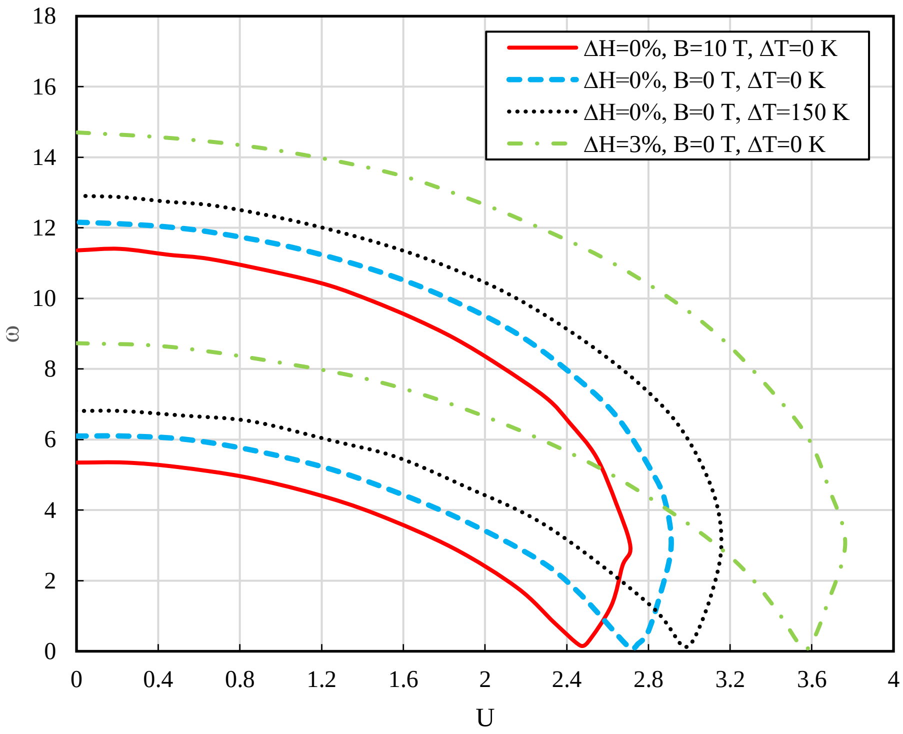

Fig. 2. Influence of environmental conditions on the vibration of the spinning system without considering surface effects.

4. Conclusion

The focus of this research, which is mostly a brief overview of fluid-conveying nanotubes, is to discuss the dynamical characteristics of fluid-conveying nanotubes as well as their size-dependent vibration behavior. Research studies on fluid-conveying nanotube vibration under environmental conditions, particularly in the thermal environment, is also being considered and the main results are summarized below:

- Fluid flow inside carbon nanotube is a crucial and challenging scientific topic.
- Nanotubes are a crucial component of current nanostructures applications due to their unique mechanical, thermal, electrical, and physical properties.
- Size-dependent approaches, such as non-local, strain gradient, and couple stress, are preferable solutions and can provide more accurate results.
- Thermal fluctuations have a considerable influence on the mechanical features of nanostructures.
- The configurations of non-linear mode forms are substantially influenced by the high-temperature environment.
- More studies are needed to determine the most effective methods to deal with the dynamic and static concerns of fluid-conveying nanotubes as well as their vibrational analysis in the thermal environment in real-world applications.

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