

Author's Accepted Manuscript

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PII: S0020-7403(16)30604-X
DOI: <http://dx.doi.org/10.1016/j.ijmecsci.2016.10.030>
Reference: MS3472

To appear in: *International Journal of Mechanical Sciences*

Received date: 1 July 2016
Revised date: 12 September 2016
Accepted date: 27 October 2016

Cite this article as: Li Li and Yujin Hu, Critical flow velocity of fluid-conveying magneto-electro-elastic pipe resting on an elastic foundation, *International Journal of Mechanical Sciences*, <http://dx.doi.org/10.1016/j.ijmecsci.2016.10.030>

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Critical flow velocity of fluid-conveying magneto-electro-elastic pipe resting on an elastic foundation

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Abstract

The paper deals with the predicting critical flow velocity of a fluid-conveying magneto-electro-elastic pipe resting on a Winkler-like elastic foundation. Taking into account the Timoshenko beam theory, the constitutive law of magneto-electro-elastic materials and Maxwell's theory, the Hamilton's principle is applied for deducing the governing equations and corresponding boundary conditions of fluid-conveying magneto-electro-elastic pipes resting on the Winkler-like elastic foundation. The closed-form solutions of the critical flow velocity are obtained for fluid-conveying magneto-electro-elastic pipes with clamped-clamped and pinned-pinned ends, and can serve as benchmarks for any future numerical results. The effects of shear deformation, Winkler-like foundation and the magnetic and voltage potentials applied in magneto-electro-elastic pipes on the critical flow velocity are discussed in detail. Results show that the magnetic and voltage potentials have a significant effect on the critical flow velocities and therefore can be used to control the critical flow velocity by choosing some appropriate values of magnetic and electric potentials.

Keywords:

Fluid-conveying pipe, Critical flow velocity, Winkler constant, magneto-electro-elastic material, Flow-induced vibration

1. Introduction

The problems encountered by the flow-induced vibration are necessary in many engineering fields (including mechanical engineering, aerospace engineering, civil engineering, energy harvesting problems and nano engineering), and therefore the studies of flow-induced vibration problems are always of practical engineering interest [1]. It has been shown by many authors [2–9] that the internal flowing fluid is a very important factor to study the flow-induced instabilities and dynamic characteristics of fluid-conveying pipes. The *critical flow velocity* of fluid-conveying pipes (also known as the divergence velocity) is of scientific interest and fundamental significance, and it in turn means that this kind of fluid-solid coupling system may cause flow-induced instability by buckling. When the flow velocity is beyond the critical flow velocity, the flow-induced vibration characteristics, which may cause large deformations, cannot be answered well by considering linear models that are applied only up for the first loss of stability (it may not satisfy the requirement of linear theory [10]), and have to be answered by using nonlinear modes. Recently, Li et al. [11] developed size-dependent Timoshenko and Euler–Bernoulli models within the framework of nonlocal strain gradient theory for predicting the flow-induced dynamical characteristics of nano/micro-scaled pipes, and found the closed-form solutions of the critical flow velocities to investigate their size-dependent effects.

Sharafkhani et al. [12] studied the flow-induced stability and transient response of electro-statically actuated micro-scaled pipes interacting with bounded compressible fluids. Dai et al. [13] developed a theoretical model for predicting the dynamics and pull-in characteristics of electrostatically actuated micro-scaled pipes containing internal fluid flow, and showed that the electric voltage can significantly influence the flow-induced instabilities and dynamic characteristics of the micropipe. Abbasnejad et al. [7] developed a Euler–Bernoulli beam model to investigate the effect of applying piezoelectric layers on the vibration stability of fluid-conveying micropipes. Li et al. [14] investigated the wave motion of single-walled carbon nanotubes under magnetic field, and showed that the phase velocity can increase by increasing the intensity of magnetic field. Dai and Wang [15] studied the vibration and stability of magnetically actuated pipes conveying fluid and found the magnetic forces have a significant effect on the dynamics of the pipe. Jabbari et al. [16] investigated the size-dependent nonlinear vibration behaviors of an electro-statically actuated micro-scaled resonator in an incompressible fluid cavity via a modified couple stress theory.

Recently, magneto-electro-elastic materials and multiferroic composites have attracted tremendous attention from the engineering and academic point of view owing to the coupling effect among their elastic, electric and magnetic fields and their adaptive properties [17–22]. In comparison with the piezoelectric or piezomagnetic (single-phase) smart materials or composites, the magneto-electro-elastic composites include new property of magneto-electricity with a secondary pyroelectric effect, which

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