Journal of Sound and Vibration ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Dynamic analysis of a vertically deploying/retracting cantilevered pipe conveying fluid

Yinlei Huo [a,b,*], Zhongmin Wang [c]

[a] School of Mechanical and Precision Instrument Engineering, Xi' an University of Technology, No. 5 South Jinhua Road, 710048 Xi'an, China

[b] Department of Packaging Engineering, Henan University of Science and Technology, No. 263 Kaiyuan Road, 471023 Luoyang, China

[c] School of Civil Engineering and Architecture, Xi' an University of Technology, No. 5 South Jinhua Road, 710048 Xi'an, China

ARTICLE INFO

Article history:
Received 10 March 2015
Received in revised form
7 September 2015
Accepted 9 September 2015
Handling Editor: L.G. Tham

ABSTRACT

Based on Euler–Bernoulli beam theory and Hamilton's principle, the differential equation of a vertical cantilevered pipe conveying fluid is derived when the pipe has deploying or retracting motion. The resulting equation is discretized via the Galerkin method in which the eigenfunctions of a clamped-free Euler–Bernoulli beam are utilized. Then, the dynamic responses and stability are discussed with regard to the deploying or retracting speed, mass ratio, and fluid velocity. Numerical results reveal that the dynamical behavior of the system is mainly affected by the flow velocity, instantaneous length of pipe, gravity, and mass ratio. For the small flow velocity, the fluid and higher mass ratio helps to stabilize the transverse vibration of the cantilevered pipe conveying fluid in both deployment and retraction modes, and the system will lose stability with the further increase of flow velocity. The critical flow velocity is mainly influenced by the instantaneous length of pipe. The additional restoring force due to gravity causes critical flow velocity to be higher for the vertically cantilevered pipe conveying fluid. Therefore, gravity is conducive to the stability the transverse vibration of the system in both deployment and retraction modes.

1. Introduction

Pipes conveying fluid are widely used in engineering systems, and in some cases, pipe length is changed with time. The casting and filling process is a typical example, in which the feeding pipe (tube) is often required to deploy or retract to ensure that the tip of pipe is always close to the liquid surface to prevent liquid splashes and simultaneously ensure the filling speed. The cantilevered pipe conveying fluid and the deploying cantilevered beam are the closest prior art to these cases. The stability of the cantilevered pipe conveying fluid and the deploying cantilevered beam have been extensively studied independently of each other.

The dynamics of pipes conveying fluid has been studied extensively over the past few decades and a lot of representative results have been achieved [1–5]. It is now well-known that a cantilevered pipe conveying fluid may lose stability at sufficiently high flow velocity via a Hopf bifurcation leading to flutter [6–8]. Additionally, the cases of simultaneous in-plane and out-of-plane lateral vibrations of small amplitude of a horizontally rotating flexible cantilevered pipe conveying fluid was investigated by Panussis, and Dimarogonas [9], who discussed the critical circular frequency of lateral vibration and critical speed of flow of the fluid-tube cantilevered system for the in-plane and the out-of-plane case. The influences of the

* Corresponding author.

http://dx.doi.org/10.1016/j.jsv.2015.09.014

rotating angular velocity and the velocity of fluid flow on the dynamical behavior of a rotating cantilevered pipe conveying fluid was studied by Yoo and Son [10], they found that the natural frequencies of a cantilevered pipe conveying fluid are proportional to the angular velocity of the pipe and a tip mass in both axial direction and lateral direction. Recently, Kheiri and Païdoussis [11] extended Hamilton's principle to the open systems, and the equation of motion of a typical flexible pipe conveying fluid system was derived via the extended form of Hamilton's principle. They found that the expression given by McIver [12] for Hamilton's principle remains valid even in the non-material volumes. In another paper, Kheiri and Païdoussis [13] investigated the dynamics and stability of a pipe conveying fluid flexibly supported at its ends based on the extended form of Hamilton's principle for open systems.

In the past two decades, many studies have focused on dynamical behaviors of deploying or retracting beams and slabs. Approximate analytical solutions for a transverse beam vibration with different end conditions were presented by Al-Bedoor and Khulief [14] for a beam with axial deployment. Meanwhile, they [15] presented a dynamic model for the vibration of a rotating and deploying beam, in which the dynamic coupling effects as well as the stiffening effect due to the beam reference rotation was considered. The linear vibration in a flexible robot arm, modeled by a moving slender beam, was analyzed by Wang and Wei [16], and Li et al. [17]. A dynamic analysis was presented for an axially translating cantilevered beam simulating the spacecraft antenna featuring time-variant velocity by Wang et al. [18]. The extended Hamilton's principle was employed to formulate the governing partial differential equations of motion. The vibrations of axially moving beams immersed in fluid were studied by Taleb and Misra [19] and Gosselin et al. [20]. When they derived the equations of motion, an "axial added mass coefficient" was implemented to better approximate the mass of fluid that stays attached to the oscillating beam while moving in the axial direction. The longitudinal and transverse vibrations of deploying or retracting beams were analyzed with regard to the moving speed and acceleration by Park et al. [21]. Their study simultaneously considered the longitudinal and transverse displacements when deriving the equations of motion, and the nonlinear von Kármán strain theory was adopted to derive the equation of longitudinal motion and transverse motion, in which the transverse motion was nonlinear and coupled with the longitudinal motion. The nonlinear dynamical behaviors of deploying-and-retreating wings in the cases of three different axially moving rates during deploying process and retreating process was investigated by Zhang et al. [22], in which Reddy's third-order theory was integrated with von

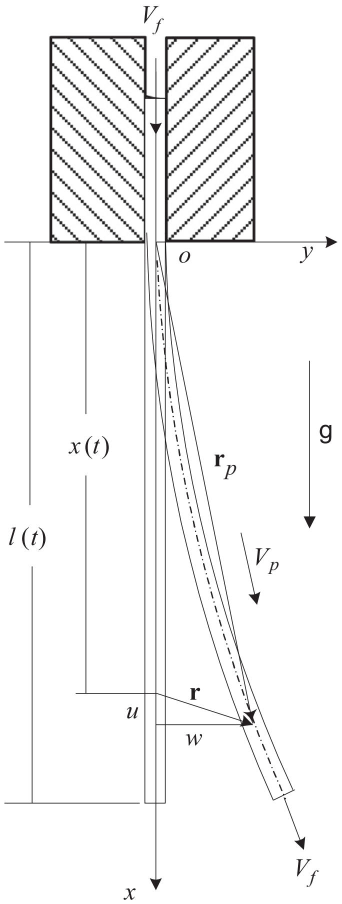

Fig. 1. The vertically deploying/recreating cantilevered pipe conveying fluid under consideration.

Please cite this article as: Y. Huo, & Z. Wang, Dynamic analysis of a vertically deploying/retracting cantilevered pipe conveying fluid, *Journal of Sound and Vibration* (2015), http://dx.doi.org/10.1016/j.jsv.2015.09.014