



Nonlinear vibration of a traveling belt with non-homogeneous boundaries

Hu Ding^{a, b, *}, C.W. Lim^{c, d}, Li-Qun Chen^{a, b, e}

^a Shanghai Institute of Applied Mathematics and Mechanics, Shanghai University, Shanghai 200072, PR China

^b Shanghai Key Laboratory of Mechanics in Energy Engineering, Shanghai University, Shanghai 200072, PR China

^c City University of Hong Kong Shenzhen Research Institute, Shenzhen 518057, PR China

^d Department of Architecture and Civil Engineering, City University of Hong Kong, Hong Kong Special Administrative Region

^e Department of Mechanics, Shanghai University, Shanghai 200444, PR China

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ABSTRACT

Free and forced nonlinear vibrations of a traveling belt with non-homogeneous boundary conditions are studied. The axially moving materials in operation are always externally excited and produce strong vibrations. The moving materials with the homogeneous boundary condition are usually considered. In this paper, the non-homogeneous boundaries are introduced by the support wheels. Equilibrium deformation of the belt is produced by the non-homogeneous boundaries. In order to solve the equilibrium deformation, the differential and integral quadrature methods (DIQMs) are utilized to develop an iterative scheme. The influence of the equilibrium deformation on free and forced nonlinear vibrations of the belt is explored. The DIQMs are applied to solve the natural frequencies and forced resonance responses of transverse vibration around the equilibrium deformation. The Galerkin truncation method (GTM) is utilized to confirm the DIQMs' results. The numerical results demonstrate that the non-homogeneous boundary conditions cause the transverse vibration to deviate from the straight equilibrium, increase the natural frequencies, and lead to coexistence of square nonlinear terms and cubic nonlinear terms. Moreover, the influence of non-homogeneous boundaries can be exacerbated by the axial speed. Therefore, non-homogeneous boundary conditions of axially moving materials especially should be taken into account.

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1. Introduction

The axially moving material is usually restrained or supported by the wheels [1–3]. Considering the constraints or supports of the wheels, the dynamic model of the moving material contains non-homogeneous boundary conditions [4,5]. As the basic components of the mechanical system, the vibration problem of the axially moving materials has been widely concerned [6–8]. Marynowski and Kapitaniak presented a state-of-the-art review of the vibration theory of axially moving continua before 2014 [9]. However, dealing with non-homogeneous boundary conditions is a challenging issue. Therefore, homogeneous boundaries are usually adopted in order to study the vibration of the moving material. The purpose of this

* Corresponding author. Shanghai Institute of Applied Mathematics and Mechanics, 149 Yan Chang Road, Shanghai 200072, PR China.

E-mail address: dinghu3@shu.edu.cn (H. Ding).

work is to evaluate the influence of the non-homogeneous boundaries on the vibration characteristics of axially moving materials.

Systems in operation are always subject to disturbances. When the system resonates, intense vibrations exhibit significant nonlinear characteristics [10–12]. Understanding these characteristics will help design optimization and vibration control. Many contributions have been achieved in the steady-state response of nonlinear vibration of traveling continua [13–15]. The boundary is always assumed to be the perfect simple support, either completely fixed or completely free. The vibrations of a moving beam on fixed supports with variable velocity are investigated [16,17]. Duan et al. studied the vibration properties of an axially moving nested cantilever beam [18]. In the case of the vibration study of the traveling belt under excitations, in most cases, the simply supported boundaries are adopted [19–24]. Therefore, it is not clear how the non-homogeneous boundary conditions affect the vibration response of the axially moving materials.

The boundary of the traveling system is not a perfectly simple support or fixed. Researchers have been constantly attempting to model realistic boundaries [25–29]. Many literature studied the vibrations of the traveling belts under different supports or constraints. Kwon and Ih studied the vibrational power flow in the moving belt passing through a tensioner [30]. Ghayesh and Khadem focused on nonlinear vibration of a conveyor belt partially supported by a distributed viscoelastic foundation [31]. Chen and Yang determined the vibration and stability of an axially moving viscoelastic beam with hybrid spring constrained [32]. Dynamics of axially moving beams with one or more intermediate support attracted the attention of many researchers [33–40]. Lee and Jang investigated the effects of the boundary conditions of axially moving beams on the energy transmission [41]. Yurddas et al. presented nonlinear vibrations analysis of axially moving strings having non-ideal mid-support conditions [42]. Gao et al. studied nonlinear vibration analysis of moving strip with inertial boundary condition [43]. Bagdatli and Uslu proposed a boundary condition between the simply supported ends and fixed ends for axially moving beams [44]. However, all of the above-mentioned studies are assumed that the continuum satisfies the homogeneous boundary condition. The effect of non-homogeneous boundary on the resonance response of axially moving materials remains to be revealed.

Non-homogeneous is an inevitable attribute of the boundary of the belt-wheel contact. Some researchers attempted to consider the effects of the non-homogeneous boundary condition. Wang and Mote evaluated the influence of the belt-wheel contact boundary conditions on the natural frequencies of the belt [1]. Yue numerical analyzed instability regions due to periodic speed variation with dynamic contact at the belt/wheel interface [45]. Hwang and Perkins analytically and experimentally analyzed the stability of the belt based on the contact of the belt wrapped about two wheels [46]. Turnbull et al. evaluated the influence of the nonlinear contact boundary conditions on the free vibration of the belt without traveling speed [47]. The effect of non-homogeneous boundary on the natural frequencies [48], the amplitude–frequency curves [49], and the steady-state response [50] of a static beam were revealed. The effect of the belt wrapping around the bounding wheels is discussed for the free vibration of traveling belts [2]. Orloske et al. studied the flexural-torsional buckling by modeling wheel misalignment as an inhomogeneous boundary condition occurring at one end [51]. By modeling the non-homogeneous boundary conditions of the two belt spans, Ding and Zu studied coupled vibration of belt-wheel systems with a clutch [52]. Coupling belt-wheel system is very complex. Although non-homogeneous boundaries are modeled in the system dynamics of belt-wheel systems, the influence of non-homogeneous boundaries on the nonlinear vibration of the system is still not revealed, especially for the impact on resonance response.

In this paper, a traveling belt with non-homogeneous boundaries is modeled. The equilibrium shape, caused by the non-homogeneous boundaries, is numerically determined. Then the nonlinear governing equation of a traveling belt is derived to describe the vibration around the equilibrium shape. Natural frequencies and primary resonance are determined by two different numerical approaches. The influences of the non-homogeneous boundaries are declared by showing the effects of the traveling speed, the radius of the wheel, and the initial tension. Numerical computations demonstrate that significant error in the calculated vibration characteristics can occur if the non-homogeneous boundary conditions are ignored.

2. Mechanical modal and governing equation

Traveling belts are often used in mechanical transmission systems. The traveling belt is usually driven or supported by rotating wheels. Fig. 1 describes the mechanical model of a traveling belt driven by two wheels. In Fig. 1, P_0 and l respectively represent the initial tension and the length of the traveling belt. The belt travels with a uniform and constant

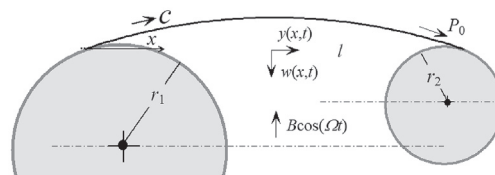


Fig. 1. Mechanical model of a traveling belt restrained by wheels.

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