Investigation of the effect of longitudinal grading of material on vibrations of axially moving systems

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ABSTRACT

For the first time, Vibrations of the axially graded Rayleigh moving beams are studied. It is supposed that the material characteristics of the system change linearly or exponentially in longitudinal direction continuously. By using the Galerkin method and eigenvalue problem, the natural frequencies and divergence of the system are computed numerically. Also, the analytical relations are extracted for the critical velocity of the system. Essential contours of velocity and stability maps are investigated for different distributions of material. As indicated, exponential and linear changes lead to more stable operation in the variable state of density and elastic modulus, respectively. Also, the results showed that increasing the elastic modulus gradient parameter or decreasing the density gradient parameter results in an increase in the natural frequency of the system and a development in the stability. Hence, alteration in the density and elastic modulus gradient parameters has a different role in the dynamic behavior of the system. The results of this study can be useful for designing and optimizing high speed non-homogeneous axial movable structures.

KEYWORDS

Axial graded materials, Gradient parameter, Moving beam, Critical velocity, Instability

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Introduction

Axial moving beams are widely used in various engineering industries. Therefore, numerous researchers have addressed the dynamic modeling and vibrational characteristics of these structures and have discussed the dynamic behavior of these structures from multiple aspects [1, 2]. In all of the available articles, the materials used in the structures were homogeneous. In recent years, engineers have improved the mechanical behavior of moving dynamics systems by enhancing material properties. To avoid possible structural limitations, the researchers introduced functionally graded materials, made from one surface to another by continuous and soft changes of two or more constituents [3-5].

According to the authors' information, in all studies on axially graded beams, it has been assumed that the configuration of the system materials changes along with the thickness while studying the dynamic behavior of the graded beams despite the importance of grading the material properties in the axial direction. No technical reports. In this regard, the dynamical analysis and stability improvement of two-axis Rayleigh moving beams have been studied comprehensively, numerically, and analytically by applying axial graded materials. The effect of several vital parameters, such as axial grading, rotational inertia, and beam velocity on the dynamical properties of the axial propulsion systems are explained. The features of the materials change in longitudinal direction based on two linear and exponential profiles. The dynamical equation of the system is derived based on Hamilton's law and compared with the equations in the literature. In the following, the reduced-order equation is obtained by the Galerkin method, and the eigenvalue problem is applied. Then, instability zones are identified for the axial moving axial beam [6, 7].

Methodology

It is assumed that the beam or boundary conditions of simple supports at a constant axial velocity *V* move in the longitudinal direction and are under *P* axial pressure. The length, cross-sectional area, and moment of inertia of the beam are indicated by *L*, *A*, and *I*, respectively. The kinetic energies and potential of the system are expressed in Equations (1-2) [8-13]:

$$T=\frac{1}{2}\int_0^L \rho_{(x)} A\left(V^2+\left(\dot{w}+Vw'\right)^2\right)dx + \frac{1}{2}\int_0^L \rho(x) I\left(\dot{w}'+Vw''\right)^2 dx \quad (1)$$

$$U=\frac{1}{2}\int_0^L\left(P\left(w'\right)^2+E_{(x)}I(w'')^2\right)dx \quad (2)$$

Where *w* (x, t) is the transverse beam. According to Hamilton's principle, it can be written:

$$\delta\int_{t_1}^{t_2}(T-U)dt=0 \quad (3)$$

By placing relationships (1-2) in relation (3), we will have:

$$\begin{aligned}&\rho_{(x)}A\left(\ddot{w}+2V\dot{w}'+V^2w''\right)+\rho'_{(x)}A\left(V\dot{w}+V^2w'\right)\\&-\rho_{(x)}I\left(\ddot{w}''+V\dot{w}'''\right)-\rho'_{(x)}I\left(\ddot{w}'+V\dot{w}''\right)\\&-\rho_{(x)}IV\left(\dot{w}'''+Vw''''\right)-2\rho'_{(x)}IV\left(\dot{w}''-Vw'''\right)\\&-\rho''_{(x)}IV\left(\dot{w}'-Vw''\right)-Pw''+E_{(x)}Iw''''\\&+2E'_{(x)}Iw'''+E''_{(x)}Iw''=0\end{aligned} \quad (4)$$

The discretization of the system equation, the transverse beam displacement is given by Equation (5):

$$\eta_{(\xi,\tau)}=\sum_{j=1}^{n}\varphi_r(\xi)\,q_r(\tau) \quad (5)$$

where q_r is the generalized dimensional coordinate, *n* is the number of essential functions, φ_r is the acceptable mode for the transverse displacement of the system.

$$\mathbf{M}\ddot{\mathbf{q}}(\tau)+\mathbf{C}\dot{\mathbf{q}}(\tau)+\mathbf{K}\mathbf{q}(\tau)=0 \quad (6)$$

where *q* is the generalized coordinate vector, *M* is the matrix of mass, *C* is the damping matrix, and *K* is the stiffness matrix of the system.

Results and Discussion

To better understand the dynamical behavior of the system, the time response of the first generalized coordinate system at different speeds is shown in Fig. 1. Initial system conditions, the static displacement of the unit is assumed to be zero for the first mode. As the speed increases, the transverse stiffness of the system decreases due to centrifugal effects. The real base frequency becomes zero, resulting in a buckling order. In this case, the dynamic response of the system without oscillation grows more durable over time, and the system becomes statically unstable. By increasing the velocity at $v = 4$, the imaginary part becomes zero, and the beam achieves its stability. As the speed increases at $v = 5$, the actual portion of the frequency increases, while the imaginary part of the system's natural frequency becomes negative, thereby amplifying the system's amplitude exponentially with time. Unlike the divergence instability, where there is no oscillation. Therefore, the magnitude of the system increases significantly with time. As a result, flutter instability is more dangerous than divergence instability for axial moving beams. In practice, for flutter speeds, any transverse motion results in dynamic ups and downs in the system [14, 15].

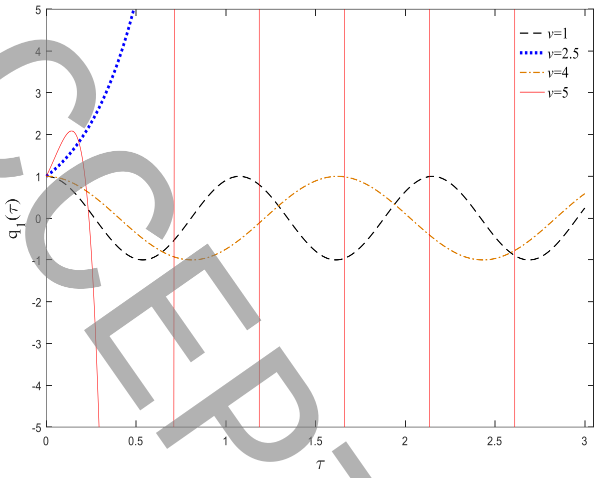

Fig .5. Dimensionless displacement response of moving axially functionally graded beam for k_f=0.5, β=0, α_E=2

Conclusions

The structural dynamics and possible vibrational instabilities of the axially-graded moving beams have been studied numerically and analytically. The distribution of material properties of the system in a longitudinal direction is considered linear and exponential. By applying the Galerkin discretization method and the problem of eigenvalues, natural frequencies, dynamic response and flutter, and diurnal instability ranges of the system based on the combined effects of beam velocity, dimensional bending stiffness, density gradient, and modulus parameters. Mathematical closed-form expressions are obtained for the critical speed of the system. Stability maps and 2D contour diagrams of critical velocity are plotted in terms of axial grading and dimensionless bending rigidity parameters for the Rayleigh and Euler-Bernoulli beams.

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