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Parametric investigation of the size-dependent axially graded Rayleigh beams subjected to a moving load on Pasternak substrate

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ABSTRACT: The vibration of axially graded Rayleigh and Euler-Bernoulli micro-beams under a moving load on Pasternak foundation is studied numerically and analytically. Accurate mathematical modeling is acquired to analyze the effect of various parameters such as longitudinal gradient parameter of material, whirling inertia factor, the stiffness of Pasternak foundation, and strain gradient parameter on the critical velocity, and cancellation mechanism and the maximum amplitude of vibrations. Natural frequencies are obtained and compared with available results in the technical literature. Closed-form expressions are extracted for dynamic magnification coefficient and maximum amplitude of free vibration. The changes in material characteristics of the system have inverse influences on the amplitude of free and forced vibrations for lower and higher values of the critical gradient parameters. It is concluded that in comparison with homogenous Euler-Bernoulli beams, in the axially graded Rayleigh micro-beams surrounded by shear Pasternak foundation. It can be controlled the cancellation and maximum free vibration phenomenon, by choosing the accurate values of gradient parameter, whirling inertia coefficient, the stiffness of foundation, and strain gradient parameter. Also, the results of the present study can be used as a criterion for the optimal design of heterogeneous structures under the moving loads.

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Critical velocity of loading

1- Introduction

In the last century, with the advent of very small mechanical and electronic components, communications, manufacturing calculations, and transmission systems have been fundamentally affected [1]. For this reason, the study of the problem of small-scale moving load systems has attracted a lot of attention [2]. Essen [3] studied the dynamics of Timoshenko micro-beams depending on the size under the moving loads. The effects of different velocities of load, mass load and material size parameter on the dynamic behavior of the structure have been investigated. Simshek [4] investigated the dynamic analysis of an embedded micro-carrier of embedded moving microspheres based on the theory of corrected coupling stress. The results showed that static sharp parameters and free vibration frequencies play an important role in the dynamic response of the system. The dynamic response of a thermo-elastic nano-beam under a moving load has been investigated by Abouelregal et al. [5]. They showed that the velocity of the moving load and the strength parameter did not affect the temperature.

In this paper, for the first time, a comprehensive study on the vibrational analysis of Rayleigh and Euler-Bernoulli axial functionally micro-beams is performed on a shear Pasternak foundation based on the high-order theory of strain gradients. Also, the conditions for the occurrence of various phenomena such as critical velocity, cancellation, and a maximum range of free vibrations of the system are reported. In the following, the theoretical model and dynamic equation of the exponential axial graded beam subjected to an external moving load are presented. The solution is then summarized and the system's natural frequencies are extracted. The results for the isotropic system have been confirmed to determine the accuracy of the solution method. The effects of various key parameters such as the amount of gradient of structural materials and the external load velocity are measured on the dynamic magnification coefficient, forced-free responses, cancellation mechanisms, and maximum of the free vibration amplitude range.

2- Methodology

It is assumed that the system is surrounded by shear Pasternak substrate with shear stiffness, k_b. 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 are expressed [6, 7]:

$$T=\frac{1}{2}\int_0^L \rho(x)A\left(\frac{\partial w}{\partial t}\right)^2 dx+\frac{1}{2}\int_0^L \rho(x)I\left(\frac{\partial^2 w}{\partial t\partial x}\right)^2 dx \tag{1}$$

$$V=-\int_0^L M\frac{\partial^2 w}{\partial x^2}dx \tag{2}$$

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where $w\ (x,\ t)$ is the transverse beam. According to Hamilton's principle, it can be written as [8, 9]:

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

By placing Eqs. (1-2) in Eq. (3), we will have [10]:

$$\begin{aligned}&\left(E(x)Iw''\right)''-l^2\left(E(x)Iw'''\right)'''-k_b w''+\rho(x)A_P\ddot{w}\\&-\rho(x)I\ddot{w}''-\rho'(x)I\ddot{w}'=P\delta(x-ut)\end{aligned} \qquad (4)$$

The discretization of the system equation, the transverse beam displacement is given as [11-13]:

$$\eta(\xi,\tau)=\sum_{j=1}^{n}\varphi_j(\xi)q_j(\tau) \qquad (5)$$

where q_j is the generalized dimensional coordinate, n is the number of essential functions, φ_j is the acceptable mode for the transverse displacement of the system [14-17]:

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

where q is the generalized coordinate vector, M is the matrix of mass, and K is the stiffness matrix of the system [18].

3- Results and Discussion

Fig. 1 shows the effect of the hardness coefficient of the shear Pasternak foundation and the strain gradient parameter on the system magnification coefficient. As these parameters increase, both lead to a stiffer system. Consequently, as these parameters increase, the dynamic coefficient curves as well as the critical velocities of the system shift to higher speeds, and in the opposite of the effect of increasing the rotational inertia factor, the system undergoes the higher forced vibration amplitude in the greater amounts of speeds.

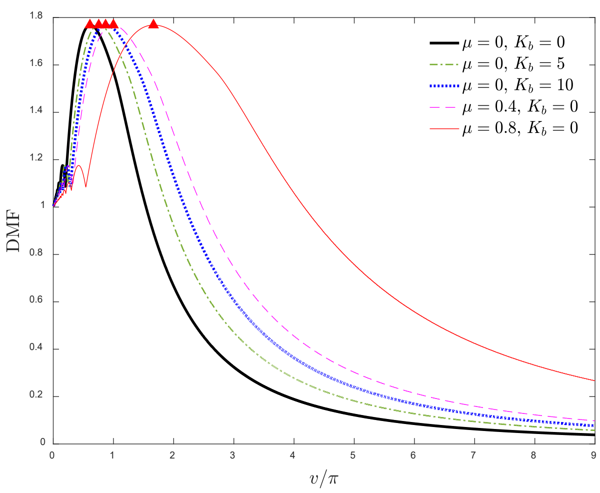

Fig. 1. Dynamic magnification coefficient of system based on dimensionless velocity for various strain gradient parameters and foundation stiffness α=0, γ=0

4- Conclusions

In this paper, the performance improvement of an axially graded micro-beam under moving load has been studied numerically and analytically. Also, there has been a comparative study between Rayleigh and Euler-Bernoulli axially graded beams to determine the effect of the whirling inertia coefficient and the longitudinal gradients of the material characteristics on the free and forced vibrational behaviors of the system. The material characteristics of the structure change continuously according to the rule of exponential. The beam is placed under a moving transverse point load with a constant value and uniform velocity. The arrow is placed under a moving transverse point with a constant value and uniform velocity. Using the Galerkin discretization method and the analysis of eigenvalues, the natural frequencies of the system are extracted and compared with the results available in the technical literature. It has been found that compared to isotropic beams under moving load, the exponentially axially graded beams show more complex and unexpected behavior under a moving load.

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