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# Bi-directional functionally graded beams: asymmetric mode and nonlinear free vibration

Ye Tang[a,b] , Xiaofei Lv[a] and Tianzhi Yang[a,c,*]

a. Department of Mechanics, Tianjin University, Tianjin, 300072, China

b. School of Mechanical and Automotive Engineering, Anhui Polytechnic University, Wuhu 241000, China

c. Tianjin Key Laboratory of Nonlinear Dynamics and Control, Tianjin，300072, China

**Abstract**

In the paper, a novel model of Euler–Bernoulli beams made of bi-directional (2D) functionally graded materials (FGMs) is presented to study the nonlinear free vibration. We found that the 2D FGMs may induce ***asymmetric modes*** in free vibration, which is distinctly different from previous research. The Hamilton's principle is applied to derive the nonlinear governing equation of the beam and associated boundary conditions based on the geometric nonlinearity. The generalized differential quadrature method (GDQM) is used to predict the vibration modes. The closed-form solutions of the nonlinear free vibration of the beam are determined by the homotopy analysis method. The effects of the material distributions, length-thickness ratio and initial amplitude on the nonlinear free vibration are discussed in details. It is notable that the nonlinear dynamic properties are highly dependent on materials properties, which suggests that the vibration behaviors of the beam may be tailored/tuned by multi-direction FGMs.

**Keywords**: Euler–Bernoulli beam; Bi-directional functionally graded materials; Geometric nonlinearity; Asymmetric modes; Free vibration

[a,c,*] Corresponding author

Email address: yang@dyn.tu-darmstadt.de