Advances in Computational Design, *Vol. 7, No. 2 (2022) 99-112*
https://doi.org/10.12989/acd.2022.7.2.099

Nonlinear static analysis of smart beams under transverse loads and thermal-electrical environments

Hayder A.K. Ali[2], Mouayed H.Z. Al-Toki*[1], Raad M. Fenjan[2], Nadhim M. Faleh[2]

[1]*Middle Technical University, Technical College, Baghdad, Iraq*
[2]*Al-Mustansiriah University, Engineering Collage P.O. Box 46049, Bab-Muadum, Baghdad 10001, Iraq*

(Received December 15, 2019, Revised November 4, 2021, Accepted November 6, 2021)

Abstract. This research has been devoted to examine nonlinear static bending analysis of smart beams with nano dimension exposed to thermal environment. The beam elastic properties are corresponding to piezo-magnetic material of different compositions. The large deflection analysis of the beam has been performed assuming that the beam is exposed to transverse uniform pressure. Based on the rule of Hamilton, the governing equations have been derived for a nonlocal thin beam and solved using differential quadrature method. Temperature variation effect on nonlinear deflection of the smart beams has been studied. Also, the beam deflection is shown to be affected by electric voltage, magnetic intensity and material composition.

Keywords: beam theory; bending; nonlocal theory; numerical analysis; static behavior; thermal load

1. Introduction

Novel materials under multi-physical fields have extraordinary behavior, especcialy when the fields are coupled to each other. As an instance, MEE materials display mechanical deformation under magnetic or electric field (Singh and Kumari 2020, Pan and Han 2005). The above fact is associated with the coupling of magnetic-electric and elastic fields (Li and Shi 2009, Guo *et al*. 2016). In such materials, the material charactristics may be especified from elastic, piezoelectric and magnetic components. Structural components (beams, shells and plates) made of MEE materials have been commonly exploited for actuating and sensing in smart machines. The material distribution in these structures may be homogenous or non-homogenous. By assuming the varying material profiles within the thickness of structures, the material distributions have been considered to be nonhomogenous. As an example, a functional graded material is a non-homogenous material in which two materials are involved and all material properties change from one material to another. In regard to the percentages and volume fractions of each material, the effective properties of the structures may be charactrized. There are several investigations on smart piezoelectric-magnetic-elastic structures having functionally graded distribution (Kumaravel *et al*. 2007).

*Corresponding author, Ph.D., E-mail: mouayedaltoki@mtu.edu.edu.iq

http://www.techno-press.org/?journal=acd&subpage=7 ISSN: 2383-8477 (Print), 2466-0523 (Online)

gradient shell structures made of porous nano-crystalline materials", *Adv. Mater. Res.*, **8**(3), 179-96. https://doi.org/10.12989/amr.2019.8.3.179.

Heydari, A. (2020), "Buckling analysis of noncontinuous linear and quadratic axially graded Euler beam subjected to axial span-load in the presence of shear layer", *Adv. Comput. Des.*, **5**(4), 397-416. https://doi.org/10.12989/acd.2020.5.4.397.

Jiang, L., Wang, Y., Wang, X., Ning, F., Wen, S., Zhou, Y. and Zhou, F.L. (2021), "Electrohydrodynamic printing of a dielectric elastomer actuator and its application in tunable lenses", *Compos. Part A Appl. S.*, **147**, 106461. https://doi.org/10.1016/j.compositesa.2021.106461.

Ke, L.L., Wang, Y.S., Yang, J. and Kitipornchai, S. (2014), "The size-dependent vibration of embedded magneto-electro-elastic cylindrical nanoshells", *Smart Mater. Struct.*, **23**(12), 125036. https://doi.org/10.1088/0964-1726/23/12/125036.

Kumaravel, A., Ganesan, N. and Sethuraman, R. (2007), "Buckling and vibration analysis of layered and multiphase magneto-electro-elastic beam under thermal environment", *Multidiscip. Model. Mater. Struct.*, **3**(4), 461-476. https://doi.org/10.1163/157361107782106401.

Li, Y. and Shi, Z. (2009), "Free vibration of a functionally graded piezoelectric beam via state-space based differential quadrature", *Compos. Struct.*, **87**(3), 257-264. https://doi.org/10.1016/j.compstruct.2008.01.012.

Liu, H., Liu, H. and Yang, J. (2018), "Vibration of FG magneto-electro-viscoelastic porous nanobeams on visco-Pasternak foundation", *Compos. Part B Eng.*, **155**, 244-256. https://doi.org/10.1016/j.compositesb.2018.08.042.

Muhammad, A.K., Hamad, L.B., Fenjan, R.M. and Faleh, N.M. (2019), "Analyzing large-amplitude vibration of nonlocal beams made of different piezo-electric materials in thermal environment", *Adv. Mater. Res.*, **8**(3), 237-257. https://doi.org/10.12989/amr.2019.8.3.237.

Pan, E. and Han, F. (2005), "Exact solution for functionally graded and layered magneto-electro-elastic plates", *Int. J. Eng. Sci.*, **43**(3-4), 321-339. https://doi.org/10.1016/j.ijengsci.2004.09.006.

Polatov, A.M., Khaldjigitov, A.A. and Ikramov, A.M. (2020), "Algorithm of solving the problem of small elastoplastic deformation of fiber composites by FEM", *Adv. Comput. Des.*, **5**(3), 305-321. https://doi.org/10.12989/acd.2020.5.3.305.

Raheef, K.M., Ahmed, R.A., Nayeeif, A.A., Fenjan, R.M. and Faleh, N.M. (2021), "Analyzing dynamic response of nonlocal strain gradient porous beams under moving load and thermal environment", *Geomech. Eng.*, **26**(1), 89-99. https://doi.org/10.12989/gae.2021.26.1.089.

Singh, A. and Kumari, P. (2020), "Analytical free vibration solution for angle-ply piezolaminated plate under cylindrical bending: A piezo-elasticity approach", *Adv. Comput. Des.*, **5**(1), 55-89. https://doi.org/10.12989/acd.2020.5.1.055.

Thai, H.T. and Vo, T.P. (2012), "A nonlocal sinusoidal shear deformation beam theory with application to bending, buckling, and vibration of nanobeams", *Int. J. Eng. Sci.*, **54**, 58-66. https://doi.org/10.1016/j.ijengsci.2012.01.009.

Zhou, H., Xu, C., Lu, C., Jiang, X., Zhang, Z., Wang, J. and Wang, L. (2021), "Investigation of transient magnetoelectric response of magnetostrictive/piezoelectric composite applicable for lightning current sensing", *Sensors Actuat. A Phys.*, **329**, 112789. https://doi.org/10.1016/j.sna.2021.112789.

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