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Global dynamics of imperfect axially forced microbeams

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ABSTRACT

This paper, for the first time, analyses the size-dependent global dynamics of imperfect axially forced microbeams and shows that how a small initial imperfection (due to improper manufacturing of microbeams) can substantially change the size-dependent global dynamical behaviour of the microsystem; moreover, it investigates the effect of small size of the microbeam on the appearance and vanishing of different chaotic and quasiperiodic motions. More specifically, the continuous expressions for the size-dependent potential energy as well as kinetic energy of the microsystem are constructed and dynamically balanced via an energy method. A transformation to a reduced-order model is performed via a weighted-residual method. The bifurcation diagrams of Poincaré maps are constructed by means of direct time-integrating the reduced-order model for the imperfect microsystem. Poincaré sections, phase-plane diagrams, time histories, and fast Fourier transforms are also plotted for some cases in order to shed light on the microsystem size-dependent global dynamics.

1. Introduction

Microbeams are present in many micromachines such as in biosensors, microactuators, micro energy harvesters, airbag accelerometers, and microswitches (Asghari, Kahrobaiyan, & Ahmadian, 2010a, Baghani, 2012; Ghayesh, Farokhi, & Amabili, 2013a). They display a size-dependent deformation behaviour due to their small size (Akgöz & Civalek, 2013; Akgöz & Civalek, 2011; Dehrouyeh-Semnani, 2014; Dehrouyeh-Semnani, BehboodiJouybari, & Dehrouyeh, 2016; Ghayesh, Amabili, & Farokhi, 2013; Hosseini & Bahaadini, 2016; Kahrobaiyan, Rahaeifard, Tajalli, & Ahmadian, 2012; Karparvarfard, Asghari, & Vatankhah, 2015; Kong, Zhou, Nie, & Wang, 2008; Mojahedi & Rahaeifard, 2016; Shafiei,Kazemi, & Ghadiri, 2016a, b; Taati, 2016); this is taken into account in this study via the modified couple stress theory (Dai, Wang, & Wang, 2015; Dehrouyeh-Semnani, Dehrouyeh, Torabi-Kafshgari, & Nikkhah-Bahrami, 2015; Farokhi & Ghayesh, 2015a, b; Farokhi, Ghayesh, & Amabili, 2013; Ghayesh & Farokhi, 2015; Ghayesh, Farokhi, & Amabili, 2013b; Ghayesh, Farokhi, & Amabili, 2014; Gholipour, Farokhi, & Ghayesh, 2015; Li & Pan, 2015; Şimşek, 2010; Tang, Ni, Wang, Luo, & Wang, 2014). In many applications, microbeams are subject to longitudinal forces due to neighbouring devices and components; these forces are time-varying under a dynamical operation. Therefore, the general form of this type of forcing can be expressed as $P_0 + P_1 \cos(\omega t)$, where P_0 denotes the mean (constant) component, P_1 represents the amplitude of the time-dependent component, and ω is the frequency of the axial load variations.

The literature on the bending, buckling, and motion characteristics of microbeams is large (Ke, Wang, Yang, & Kitipornchai, 2012; Luo, Francis, & Liu, 2008; Şimşek & Reddy, 2013; Xia, Wang, & Yin, 2010; Zhang, He, Liu, Shen, & Lei, 2015). For

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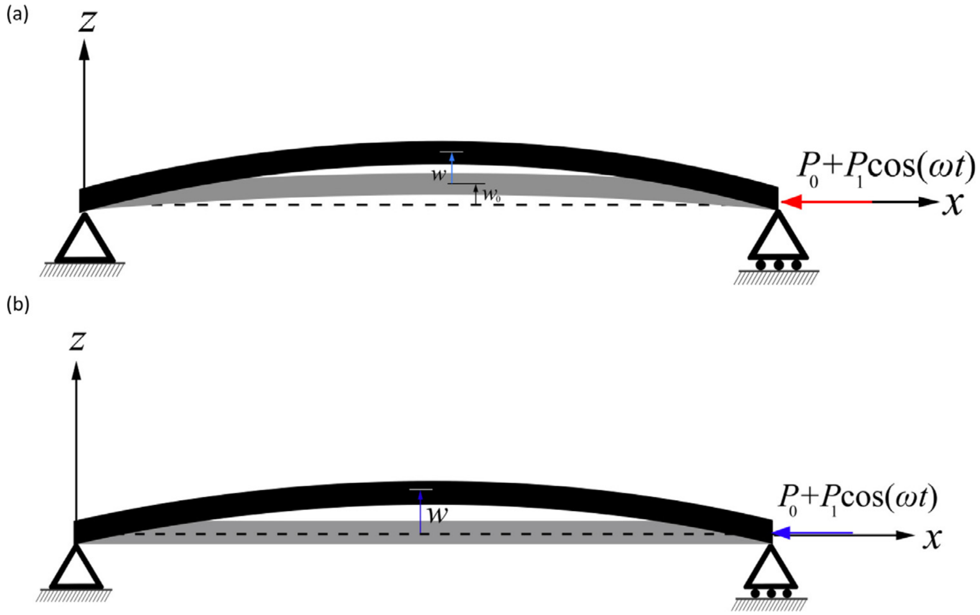

Fig. 1. Shecmatic representation of an axially forced microbeam: (a) imperfect; (b) perfect.

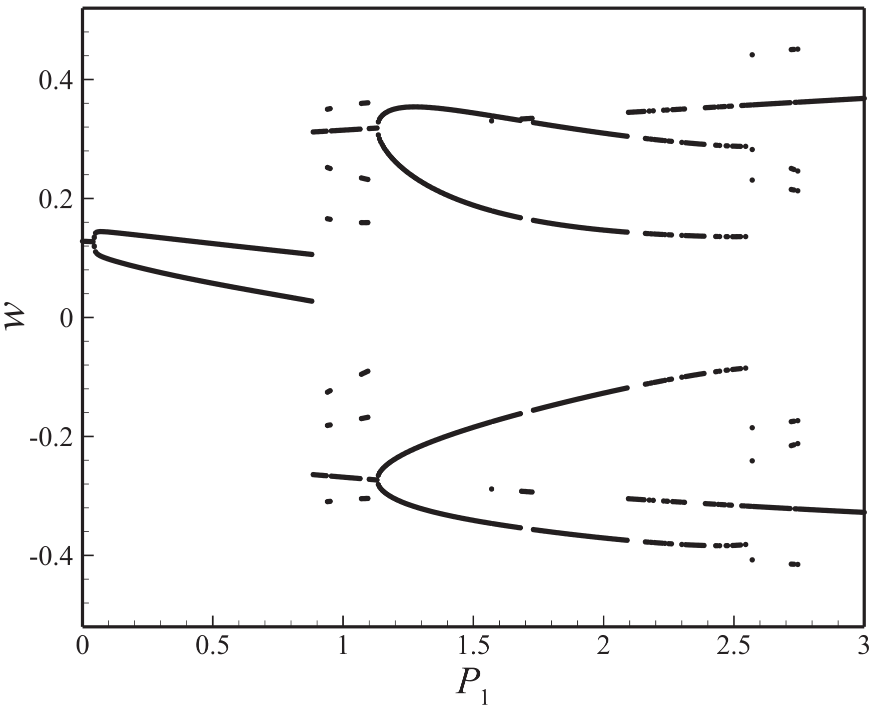

Fig. 2. Bifurcation diagram of Poincaré sections for increasing amplitude of the axial force variations on the *imperfect* system with $P_0 = 11.0$ and $A_0 = 0.01$.

instance by: Salamat-talab, Nateghi, and Torabi (2012), who analysed the statics and motion characteristics of a functionally graded microbeam modelled via a third-order shear-deformable theory; Medina, Gilat, and Krylov (2012), who obtained the buckling response of an initially curved microbeam subject to an electrical load; Ramezani (2012), who developed a size-dependent nonlinear model of a Timoshenko microbeam; Ansari, Gholami, Faghih Shojaei, Mohammadi, and Sahmani (2013), who employed a strain gradient elasticity theory in order to analyse the buckling behaviour of a functionally graded microbeam; Asghari, Ahmadian, Kahrobaiyan, and Rahaeifard (2010b), who examined the dynamics of a functionally graded microbeam by means of the modified couple stress theory; Wang, Xu, and Ni (2013) and Ma, Gao, and Reddy (2008), who