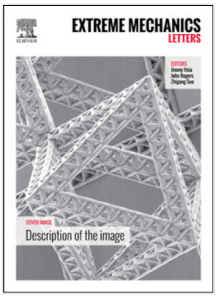
Accepted Manuscript



Mechanical design and analysis of a crawling locomotion enabled by a laminated beam

Zhe Yang, Liangliang Zhu, Botong Li, Shuocheng Sun, Youlong Chen, Yuan Yan, Yilun Liu, Xi Chen

PII: S2352-4316(16)30078-5
DOI: http://dx.doi.org/10.1016/j.eml.2016.03.014
Reference: EML 146

To appear in: *Extreme Mechanics Letters*

Received date: 18 December 2015
Revised date: 15 March 2016
Accepted date: 17 March 2016

Please cite this article as: Z. Yang, L. Zhu, B. Li, S. Sun, Y. Chen, Y. Yan, Y. Liu, X. Chen, Mechanical design and analysis of a crawling locomotion enabled by a laminated beam, *Extreme Mechanics Letters* (2016), http://dx.doi.org/10.1016/j.eml.2016.03.014

Mechanical design and analysis of a crawling locomotion enabled by a laminated beam

Zhe Yang [a], Liangliang Zhu [a], Botong Li [b], Shuocheng Sun [a], Youlong Chen [a], Yuan Yan [a], Yilun Liu [c*], Xi Chen [d*]

[a] *International Center for Applied Mechanics, State Key Laboratory for Strength and Vibration of Mechanical Structures, School of Aerospace, Xi'an Jiaotong University, Xi'an 710049, China*

[b] *College of Mechanical Engineering, Beijing University of Technology, Beijing 100124, China*

[c] *State Key Laboratory for Strength and Vibration of Mechanical Structures, School of Aerospace Engineering, Xi'an Jiaotong University, Xi'an 710049, China*

[d] *Columbia Nanomechanics Research Center, Department of Earth and Environmental Engineering, Columbia University, New York, NY 10027, USA*

Abstract

This work presents an innovative design of a simple crawling locomotion machine, which is a bilayer beam and crawls forward through periodically bending and unbending of the beam. Here, the beam has different friction coefficients at the two ends of contact surface between the beam and the substrate. During bending and unbending of the beam, the friction force distribution at the contact surface is asymmetrical, thus a net forward speed (towards the high friction coefficient direction) is generated. Both finite element method (FEM) simulation and theoretical model are employed to clarify the crawling mechanism and to achieve an optimal crawling performance. The effects of geometrical and mechanical parameters of the bilayer beam, as well as the periodically bending actuation on the crawling performance are investigated. A better crawling performance could be achieved with larger beam length, larger bending angle, and higher actuation frequency. An optimum value of the frictional coefficient gradient is found to be ~0.05 m^{-1}. Besides the asymmetry of the friction coefficient, our results have shown the asymmetry of the geometry of the bilayer beam can also achieve the locomotion. The simple locomotion mechanism presented in this work is applicable not only for macroscale, but also for nanoscale, which may inspire a series of new architectures of soft robot from macroscale to nanoscale.

Keywords: Asymmetric friction coefficient; Crawling locomotion; Soft machine; Nano-robots; Mechanical analysis

* Corresponding authors: yilunliu@mail.xjtu.edu.cn (Y.L.) and xichen@columbia.edu (X.C.)