Numerical Simulation of a Bio-inspired, Bistable Plate System.

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Abstract. In this paper, the authors aim to numerically simulate the experimentally observed dynamic and static behaviour of a bi-directionally curved, buckled, plate-based bistable system inspired from the Venus flytrap. This system consists of a thin rectangular plate with a slot along its centre line thus creating two sub-plates. Displacement constraints placed on the free, cantilevered edges of the sub-plates cause the bending and twisting of the plate thus giving rise to bi-directional curvature and the buckling bistability. It has been seen experimentally that this system shows a unique hysteretic behaviour during the snap through phenomena. The Poisson-Kirchhoff classical thin plate theory has been used to explain this unique hysteric behaviour. Initially, the parameters governing the snap-through have been identified and studied. A static analysis has been performed to formulate the stiffness of the system followed by a dynamic analysis by assuming a sinusoidal force input.

Introduction

The usefulness of bistable systems in broadband energy harvesting has already been proved [1]. Several methods have been used to create bistable systems [1]. Recently, Qian et al [2] developed a plate-based bistable system inspired from the leaf blades of the Venus flytrap. Although several plate-based bistable systems have already been rigorously studied [3], this is a novel bistable system which requires no external bistability inducing mechanisms, moreover the unique bending and twisting observed due to the end displacement constraints have not been studied numerically as per the knowledge of the authors.

Building on to the existing self-contained bistable system in [3], the authors have proposed a modified version of this system as shown in Fig.1(d) to improve repeatability and reduce variability. The sheet metal plate is given a lateral in-plane displacement as indicated in Fig.1(a) while clamping, this induces bi-directional curves (Fig.1(b) and Fig.1(c)) in the plate, thus causing the bistability. The stiffness curve of the system has been determined experimentally by giving small incremental displacements at point P (Fig.1(d)) in the transverse direction and measuring the opposing force exerted by the system at each displacement as shown in Fig.1(e). Using the Poisson-Kirchhoff's classical thin plate theory, the unique stiffness curve of the bistable system obtained experimentally has been explained. Using the developed numerical model, the response of the system for an external sinusoidal forcing function has been determined.

Results and Discussion

Apart from the snap-through mechanism observed in conventional bistable systems, it has been observed that under quasistatic conditions the path followed by the system from stable state A to B is not the same as that taken by the system from stable state B to A. The authors have attempted to explain this hysteretic behaviour, numerically.Fig.1(f) shows stiffness curve of the bistable system.

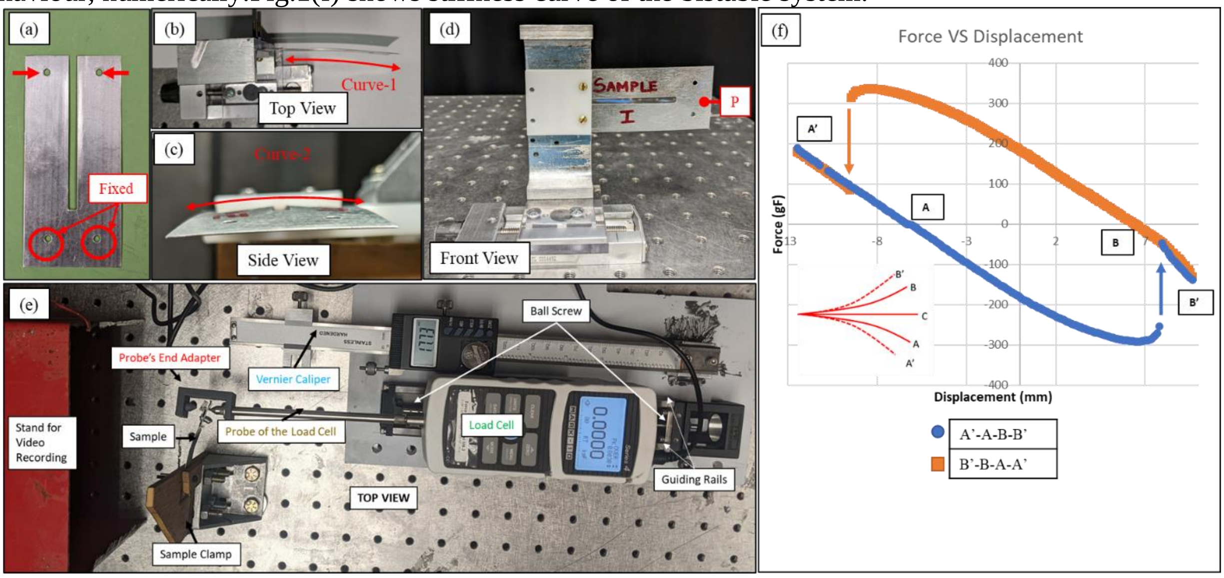

Figure 1: (a) Sheet metal plate (b) Top view of the bistable system. (c) Side view of the bistable system. (d) Front view of the bistable system. (e) Experimental Apparatus. (f) Force VS Displacement curve

References

[1] R L Harne and K W Wang (2013) A Review of the Recent Research on Vibration Energy Harvesting via Bistable Systems. Smart Mater. Struct. 22 023001.

[2] F. Qian, M. R. Hajj, and L. Zuo (2020) Bio-inspired bi-stable piezoelectric harvester for broadband vibration energy harvesting, Energy Conversion and Management, Volume 222, 113174.

[3] A. F. Arrieta, P. Hagedorn, A. Erturk, and D. J. Inman (2010) A Piezoelectric Bistable Plate for Nonlinear Broadband Energy Harvesting, Appl. Phys. Lett. 97, 104102.