On the Statics and Torsional Dynamics of Coupled Kresling Origami Springs

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Abstract. Often the ancient Japanese art form Origami has inspired engineers to develop functional engineering systems. We are particularly interested in Kresling pattern origami and developed functional Kresling Origami Springs (KOS). In this work we theoretically and experimentally study the coupled KOSs and the varied characteristics that entail under torsional loads. It is demonstrated that by varying the total height of the coupled KOS the torsional stiffness can be readily tuned. The preliminary analysis under dynamic loading exhibited interesting complex dynamics.

Introduction

In recent times, origami has emerged from being just an art to a platform for building functional engineering systems with versatile characteristics. There are various patterns of origami that have been studied in the literature for engineering applications and one such pattern that has garnered significant attention is Kresling pattern origami. With its high load bearing capacity, tunability, programmability and unique deployment characteristics it inspired the design of flexible antennas, selectively collapsible structures, robot manipulators and crawling and peristaltic robots. However, the traditional origami materials often employed introduce inevitable uncertainties and limit the functionality with low fatigue life. Overcoming these challenges, using multi-phase materials functional and durable Kresling Origami Springs (KOS) with mono-stable, bi-stable potential and Quasi-Zero Stiffness (QZS) characteristics are developed [1]. Using the 3D printed KOS, we intend to study the rich dynamics of these structures which for the most part have been limited to theoretical studies. Towards that goal in this work, we experimentally study and analyse the coupling in the longitudinal and rotational degrees of freedom of the KOS. With that understanding we developed Kresling Origami Spring Pair (KOSP) with two KOSs of opposite chirality connected together as shown in Fig.1(a). The KOSP is pre-compressed to a certain height, u_T, at which height as the pure rotation is prescribed at one end, the intermediate plane rotates and translates between the two fixed ends in the process compressing one constitutive KOS while expanding the another by an equal amount. As the direction of rotation is reversed the expansion and compression happens in the opposite KOSs as shown in Fig 1(b). The measured torque is the net effective restoring torque of the individual KOSs to the deformation.

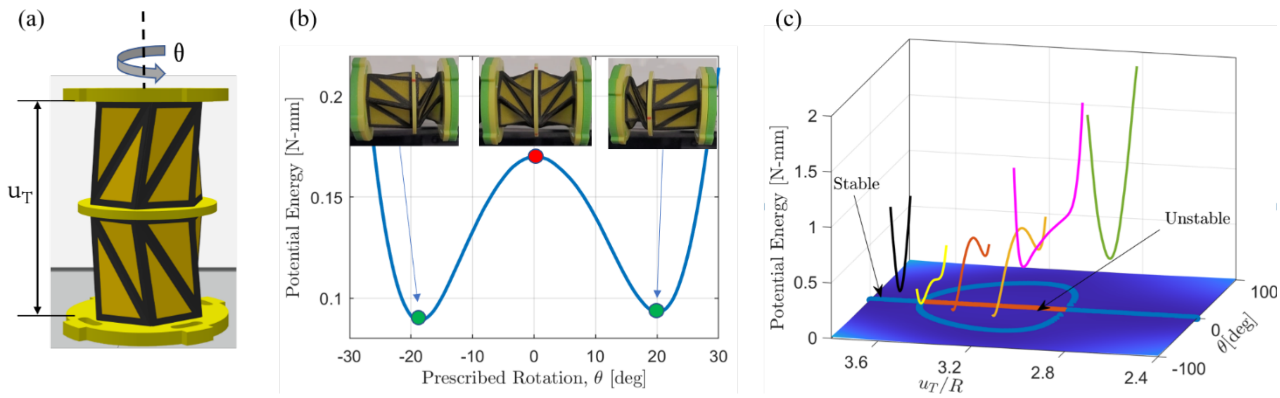

Figure 1: (a) Schematic of the Kresling Origami Spring Pair (KOSP); (b) Calculated potential energy from experimentally measured torque, in-figures show form of the KOSP at stable and unstable equilibria; (c) Potential energy tuning with pre-compression of KOSP (experimental), surface plot shows analytical prediction using truss model [2].

Figure 1 (c), shows potential energy tuning of the KOSP with the pre-compressed height, starting at left the KOSP is monostable and as the KOSP is compressed, it undergoes super critical pitchfork bifurcation and the KOSP becomes bi-stable in torsion. On further compression at about u_T/R~2.8 the KOSP becomes a QZS spring and on further compression the KOSP becomes monostable again. We find that with careful selection of design parameters interesting characteristics such as multi-stability and asymmetricity can also be realized. Based on our initial observation the varied static characteristics of the KOSP entail very interesting complex dynamic responses that can be manipulated for torsional vibration isolation, torsional wave guiding etc.

References

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[2] R. Masana, M. F. Daqaq, Equilibria and bifurcations of a foldable paper-based spring inspired by kresling-pattern origami, Phys. Rev. E100,063001 (2019).