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Multistable Mechanical Metamaterials for 3D Positioning

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Mechanical metamaterials obtain effective properties mainly from their elementary structure rather than constituent materials [1]. Multistable mechanical metamaterials are kinematic structures with multiple stable configurations. Switching between stable configurations may happen due to an external stimulus. The configuration transition is usually caused by exploiting elastic instability to develop programmable materials [2]. As a type of elastic instability, snap-through instability can cause a structure to instantaneously jump from one stable state to another. The motion associated with the geometrical changes can potentially be used for positioning and switching devices [3,4]. In most previous work, the motion is usually confined to one direction due to transitions of planar stable configurations, which limits applications. Here, we present and explore a multistable metamaterial with motions in multiple directions. Its unit cell is composed of two parallel hexagonal frames which contain buckling elements. A three dimensional multilayer multistable metamaterial is obtained by distributing this hexagonal unit cells in three dimensions. This metamaterial can not only achieve vertical motion with transitions of different planar stable configurations but also certain rotations as a consequence of various spatial stable states. This programmable behavior implies that this type of multistable metamaterials can be used, among others, for three dimensional positioning applications. Utilizing numerical models, the nonlinear mechanics of this type of metamaterials is analyzed. The kinematics, critical loads and multiple configurations are studied by finite element techniques and experimental observations. Furthermore, for each layer, the number of stable configurations and relevant motion range are connected with the number of unit cells. Numerical models are employed to investigate effects of cells and used to provide design principles for the proposed multistable mechanical metamaterials.

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