Random-access mechanical memory with a spin: path-dependent control of independent bistable beams in a rotating frame

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Abstract

Controlling transition sequences in multistable mechanical systems traditionally relies on complex interactions between elements, making the design of specific sequences challenging. Here, we present a novel strategy that achieves path-dependent switching in a system of non-interacting bistable (clamped-clamped) beams, which encode memory through their stable states, using a single control functional parameter in a rotating frame of reference. By controlling the time series of angular position as an input function, we leverage the two fictitious forces that emerge in the rotating frame: the Centrifugal and Euler forces. The Centrifugal force scales as the square of angular velocity and pointing radially outward. The Euler force is proportional to the angular acceleration (the derivative of the angular velocity and points perpendicular to the radius, with a direction that can be switched by decelerating vs. accelerating the angular dynamics. These coupled forcing terms create distinct stability domains that enable deterministic but path-dependent transitions.

Through precision experiments and theoretical modeling using a von Mises truss system as a base framework, we demonstrate that the transition boundaries between stable states can be precisely tuned through geometric parameters, including the end-to-end shortening of the beams, their tilt orientation relative to the radial direction, and a heterogeneous and asymmetric bending stiffness of the beams. When multiple beams are positioned within the rotating frame, their transition boundaries can be accurately designed to intersect, leading to multiple possible transition sequences depending on the path taken in the space of angular velocity and acceleration input signals. We show that non-elliptical orbits in this (angular) velocity-acceleration space can enable the access of states that are otherwise unreachable by simple harmonic driving, thereby providing complete control over the individual beam states.

For a three-beam system, we achieve fully connected transition sequences with minimal Hamming distance between their binary states, demonstrating the potential for random-access mechanical memory. Our approach enables the design of programmable multistable

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systems without requiring complex coupling between elements. This strategy significantly simplifies the implementation of mechanical computing and memory systems, with potential applications in soft robotics, rewritable mechanical memory, and microfluidic devices.