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Exploiting the nonlinear deformation of mechanical metamaterials for engineering applications

Etienne Leclerc[1,2*], Hossein Vatandoost[3], David Melancon[1,2*]
[1]Department of Mechanical Engineering, Polytechnique Montreal, Montreal, Canada
[2]Research Center for High Performance Polymer and Composite Systems (CREPEC), McGill University, Montréal, Canada
[3]National Research Council Canada (NRC), Boucherville, Canada
*etienne.leclerc@polymtl.ca, david.melancon@polymtl.ca

ABSTRACT

Adaptive and responsive mechanical systems have significant potential in engineering applications requiring dynamic performance tuning. This work investigates a novel class of deformable mechanical metamaterials that leverage centrifugal forces to induce controlled structural transformations. Such materials exhibit nonlinear deformation characteristics, enabling passive adaptation to external loading conditions.

We design a structure that integrates a flexible network of beams, capable of undergoing sudden geometric reconfiguration above a critical rotational speed. Using nonlinear finite element simulations, we demonstrate that under specific operating conditions, these beams collapse, resulting in a transformation of the system's overall mechanical properties. By carefully controlling the design parameters, such as beam thickness, orientation, and relative density, we showcase the ability to modulate the effective stiffness and structural response of the material as a function of rotational speed. To validate our simulation results, we collaborate with the National Research Council of Canada to fabricate prototypes using additive manufacturing of composite materials. The findings of this study open new possibilities for rotating machinery, adaptive aerospace structures, energy absorption systems, and vibration control applications, offering a pathway toward the next generation of dynamically tunable mechanical systems.