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How to imitate natural spring-loaded snapping movement without losing energy

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Venus flytraps do it, trap-jaw ants do it, and now materials scientists at the University of Massachusetts Amherst can do it, too—they discovered a way of efficiently converting elastic energy in a spring to kinetic energy for high-acceleration, extreme velocity movements as nature does it.

In the physics of human-made and many natural systems, converting energy from one form to another usually means losing a lot of that energy, say first author Xudong Liang and senior researcher Alfred Crosby. "There is always a high cost, and most of the energy in a conversion is lost," Crosby says. "But we have discovered at least one mechanism that helps significantly." Details are in *Physical Review Letters.*

Using high-speed imaging, Liang and Crosby measured in fine detail the recoiling, or snapping, motion of elastic bands that can reach accelerations and velocities similar to many of the natural biological systems that inspired them. By experimenting with different elastic band conformations, they discovered a mechanism for imitating ant and flytrap fast-motion, high-power impulse events with minimal energy loss.

Liang, who is now on the faculty at Binghamton University, and Crosby are part of a group that includes roboticists and biologists led by former UMass Amherst expert Sheila Patek, now at Duke University. She has studied the mantis shrimp's extremely rapid raptorial appendage-snapping motion for years. Their multi-institution team is supported by a U.S. Army Multidisciplinary University Research Initiative (MURI) grant funded by the U. S. Army Research Laboratory and its Research Office.

In Liang's observations and experiments, he discovered the underlying conditions where energy is most conserved—plus the fundamental physics—and presents what Crosby calls "some really beautiful theory and equations" to support their conclusions. "Our research reveals that internal geometric structures within a spring play a centrally important role in enhancing the energy conversion process for high-power movements," Crosby notes.

The secret turned out to be adding strategically placed elliptical—not circular—holes to the elastic band, Liang says. "Maintaining efficiency is not intuitive, it's very difficult to guess how to do it before you experiment with it. But you can start to form a theory once you see how the experiment goes over time. You can start to think about how it works."

He slowed the action to watch the snapping motion in a synthetic polymer that acts like a rubber band.

Liang discovered that the structural secret is in designing a pattern of holes. "With no holes everything just stretches," he notes. "But with holes, some areas of the material will turn and collapse." When plain bands are stretched and recoiled, less than 70% of the stored energy is harnessed for high-power movement, the rest is lost.

By contrast, adding pores transforms the bands into mechanical meta-materials that create motion through rotation, Liang explains. He and Crosby demonstrate that with meta-materials, more than 90% of the stored energy is used to drive movement. "In physics, bending accomplishes the same movement with less energy, so when you manipulate the pattern of the pores you can design the band to bend internally; it becomes high-efficiency," Crosby adds.

"This shows that we can use structure to change properties in materials. Others knew this was an interesting approach, but we moved it forward, especially for high-speed movement and the conversion from elastic energy to kinetic energy, or movement."

The two hope this advance will help roboticists on their MURI team and others with a performance goal to help them design high-efficiency, rapid kinetic robotic systems.

Liang says, "Now we can hand over some of these structures and say, 'Here's how to design a spring for your robots.' We think the new theory opens up a lot of new ideas and questions on how to look at the biology, how the tissues are structured or their shells are configured to allow rotation that we show is the key," he adds.

More information: Xudong Liang et al, Programming Impulsive Deformation with Mechanical Metamaterials, *Physical Review Letters* (2020). DOI: 10.1103/PhysRevLett.125.108002

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