Sound-proof metamaterial inspired by spider webs

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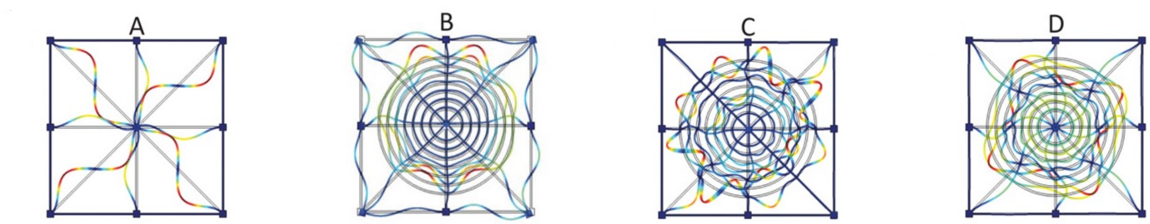

Different vibration mode shapes of the spider-web-inspired acoustic metamaterial. Credit: M. Miniaci et al. ©2016 AIP Publishing

(Phys.org)—Spider silk is well-known for its unusual combination of being both lightweight and extremely strong—in some cases, stronger than steel. Due to these properties, researchers have been developing spider-silk-inspired materials for potential applications such as durable yet lightweight clothing, bullet-proof vests, and parachutes.

But so far, the acoustic properties of spider webs have not yet been explored. Now in a new study, a team of researchers from Italy, France and the UK has designed an acoustic metamaterial (which is a material made of periodically repeating structures) influenced by the intricate spider web architecture of the golden silk orb-weaver, also called the Nephila spider.

"There has been much work in the field of metamaterials in recent years to find the most efficient configurations for wave attenuation and manipulation," coauthor Federico Bosia, a physicist at the University of Torino in Italy, told *Phys.org*. "We have found that the spider web architecture, combined with the variable elastic properties of radial and circumferential silk, is capable of attenuating and absorbing vibrations in wide frequency ranges, despite being lightweight."

By modeling different versions of the new spider-web-inspired acoustic metamaterial, the researchers demonstrated that the new design is more efficient at inhibiting low-frequency sound and is more easily tuned to different frequencies than other sound-controlling materials. Combined with the stiffening mechanical properties and the heterogeneity of spider silk, the tunable acoustic properties demonstrated here suggest that spider-web-inspired metamaterials could lead to a new class of applications for controlling vibrations. Possibilities include earthquake protection for suspended bridges and buildings, noise reduction, sub-wavelength imaging, and acoustic cloaking.

The acoustic advantages of the spider web arise, at least in part, from the concentric circles, or "rings," of the web. These rings resonate at a particular frequency when exposed to vibrations. Based on this natural architecture, the researchers designed the acoustic metamaterial to have square units containing resonating rings with supporting ligaments that radiate outward from the center of the rings. The design could be incorporated into many diverse man-made structures.

"One could design vibration-isolated (and possibly earthquake-resilient) suspended bridges or tensile structures exploiting the proposed design: a periodic repetition of the spider-web-like units integrated among the main and suspender cables," Bosia said. "At smaller scales, the same type of structures could be used for wave attenuation in the acoustic range, such as for sound abatement deriving from road or rail infrastructures."

The metamaterial is highly tunable because its geometry is defined by five parameters—which is more than traditional acoustic materials—and each of these parameters can be independently controlled to produce a vast number of designs that respond to different acoustic frequencies. The frequency range that is inhibited by these materials is called the band gap, and here the researchers showed that spider-web-inspired acoustic metamaterials can have wide band gaps, with large ranges of tunability.

In the future, the researchers plan to further investigate the unusual vibration-reducing properties of spider webs, and how to take advantage of them for applications.

"We want to study the vibrational properties of a single spider web (as opposed to its periodic repetition as in the present work), to try to understand if its structure allows vibration attenuation and focusing effects at different locations that are functional to the spider's needs," Bosia said. "In general, we also aim to look at other possible bio-inspired designs for metamaterials, possibly based on hierarchical architectures, for attenuation at multiple frequency scales. We are also trying to bring some of these concepts to large scales, for applications such as seismic shields."

More information: M. Miniaci, A. Krushynska, A. B. Movchan, F. Bosia, and N. Pugno. "Spider web-inspired acoustic metamaterials." *Applied Physics Letters*. (2016), 109, 071905; DOI: 10.1063/1.4961307