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Modeling and analysis of piezoelectric energy harvesting and its extension to metamaterial-based design

Statement of the Problem: Piezoelectric energy harvesting (PEH) is recognized as a promising solution for converting vibration energy into usable electricity, because it has high energy density and can be easily miniaturized for use in wireless sensor nodes. Metamaterial-based energy harvesting (MBEH) has been recently proposed as a breakthrough technology to drastically enhance the output electric power generated by a piezoelectric device. The metamaterial refers to an artificial structure, engineered to possess exotic properties such as a phononic bandgap. The phononic bandgap is defined as a certain range of frequencies within which mechanical waves cannot be transmitted through phononic crystals (PnC). This keynote talk mainly discusses about how the phononic bandgap contributes to the enhancement of energy harvesting performance.

Methodology & Theoretical Orientation: Two innovative design concepts for the MBEH using the phononic bandgap will be presented as: (1) a quarter-wave stack (QWS) parabolic mirror for energy focusing and (2) a defect-mode PnC for energy localization. When the phase between the incident and reflected waves are different, destructive interference can occur, thereby causing diminution of energy focusing. The backbone idea of the QWS unit cell configuration is to make all the reflected and incident waves in-phase at the focal region for maximizing the reflectivity while minimizing the wave cancellation. The supercell is configured by removing unit cells from the perfect PnC (breaking the periodicity). A narrow passband within the phononic bandgap exhibits resonance natures of the cavities, namely the defect mode, which traps the energy.

Findings: The superposition of the incident and reflected waves can form standing wave patterns, thereby knowing where the peak amplitude occurs. In addition, larger the supercell size guarantees higher the output electric power.

Conclusion & Significance: The phononic bandgap can be used to focus and/or localize mechanical waves on the piezoelectric device for highly-dense energy harvesting.

Recent Publications

1. Yoon H, Kim M, Park C-S and Youn B D (2018) Time-varying output performances of piezoelectric vibration energy harvesting under nonstationary random vibrations. Smart Materials and Structures 27:015004.
2. Jung B C, Yoon H, Oh H, Lee G, Yoo M, et al. (2016) Hierarchical model calibration for designing piezoelectric energy harvester in the presence of variability in material properties and geometry. Structural and Multidisciplinary Optimization 53:161–173.
3. Yoon H, Youn B D and Kim H S (2016) Kirchhoff plate theory-based electromechanically-coupled analytical model considering inertia and stiffness effects of a surface-bonded piezoelectric patch. Smart Materials and Structures 25:025017.
4. Yoon H and Youn B D (2014) Stochastic quantification of electric power generated by a piezoelectric energy harvester using a time-frequency analysis under non-stationary random vibrations. Smart Materials and Structures 23:045035.
5. Lee S, Youn B D and Jung B C (2009) Robust segment-type energy harvester and its application to wireless sensor. Smart Materials and Structures 18:095021.

Biography

Byeng D Youn received the BS Degree from Inha University, Republic of Korea, in 1996, MS Degree from Korea Advanced Institute of Science and Technology (KAIST), Republic of Korea, in 1998, and PhD Degree from the University of Iowa, USA, in 2001. He is currently a Full Professor with the Department of Mechanical and Aerospace Engineering, Seoul National University, Republic of Korea. His current research topics include prognostics and health management, reliability-based design optimization, energy harvesting, and statistical model validation. His dedication and efforts in research have garnered substantive peer recognition, resulting in notable awards including the ASME IDETC Best Paper Awards in 2001 and 2008, the ISSMO/Springer Prize for a Young Scientist in 2005, the IEEE PHM Data Challenge Competition Winner in 2014, the PHM Society Data Challenge Competition Winner in 2014, 2015, and 2017, and a highly cited research paper on Applied Energy in 2015.

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