Investigation on Improving the Performance of Mechanical Metamaterials Expanded by Sound Waves

K. Hirano[1,*], M. Narita[1] and S. Arikawa[2]

[1]Graduate School of Science and Technology, Meiji University, Japan
e-mail: ce252074@meiji.ac.jp

[2]Department of Mechanical Engineering Informatics, Meiji University, Japan
e-mail: arikawa@meiji.ac.jp

KEYWORDS: *Mechanical Metamaterial, Actuator, Regular Structure, Sound Waves, Smart Material.*

This study proposes a hexagonal unit cell with an asymmetric membrane that undergoes expansion deformation under acoustic excitation. The proposed design aims to realize a two-dimensional periodic structure driven by contactless and wireless acoustic energy transfer, eliminating the need for conventional wiring or onboard power supplies. First, finite element analysis was conducted to investigate the deformation behavior of the proposed structure under sound-wave excitation. Based on the analytical model, test specimens were fabricated using a 3D printer, and experiments were performed to validate the deformation characteristics. In the experiments, the membrane was excited by acoustic waves incident normal to its surface. Under acoustic excitation at the resonant frequency of 50 Hz, the membrane exhibited stable expansion deformation, and the expansion behavior was maintained even when multiple unit cells were connected vertically and horizontally to form a two-dimensional periodic structure. Quantitative evaluation showed that the static expansion displacement increased from 5 μm in a single unit cell to 10 μm after interconnecting the unit cells into a periodic structure. Moreover, the equilibrium position shifted by 20 μm toward the expansion direction, suggesting that structural periodicity promotes both static and dynamic expansion responses under acoustic excitation. The proposed expansion behavior under acoustic excitation was confirmed through both numerical analysis and experimental validation.

In addition, theoretical investigations were conducted to clarify the conditions required to sustain the expanded state by examining the curvature and bending moments induced by membrane resonance. These findings demonstrate the potential of acoustically driven mechanical metamaterials [1] for lightweight, adaptive, and wirelessly actuated structures.

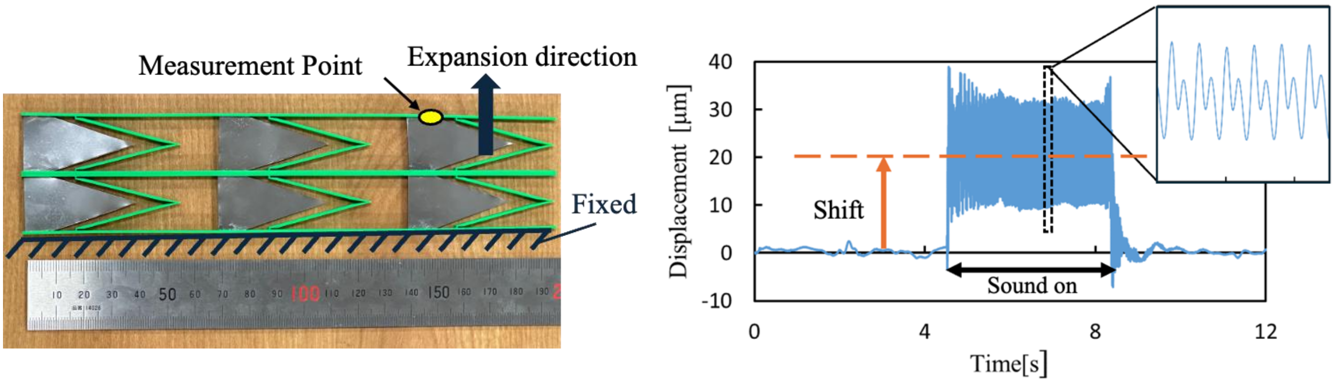

Figure 1. Test specimens and experimental results

[1] Pengcheng Jiao, Jochen Mueller , Jordan R. Raney , Xiaoyu (Rayne) Zheng, Amir H. Alavi, Mechanical metamaterials and beyond, Nature Communications (2023)14:6004