Data Article

Numerical simulation data for the dynamic properties of rainbow metamaterials

Han Meng,*, Dimitrios Chronopoulos, Adriano T. Fabro

Institute for Aerospace Technology & The Composites Group, University of Nottingham, NG8 1BB, UK
Department of Mechanical Engineering, University of Brasilia, 70910-900, Brazil

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Abstract
Simulation data are presented for identifying and analysing the dynamic properties of the rainbow metamaterials as presented in the articles “Rainbow metamaterials for broadband multi-frequency vibration attenuation: numerical analysis and experimental validation” (Meng et al., 2019 [1]) and “Optimal design of rainbow elastic metamaterials” (Meng et al., 2019 [2]). In this data article, the frequency response functions and mode shapes of the rainbow metamaterials are numerically calculated by Finite Element models set up in Ansys Mechanical APDL. Harmonic analysis was performed to figure out the receptance function values of the rainbow metamaterials within the frequency regime 0–500 Hz. Modal analysis was applied to estimate the mode shapes, which could be used to explain the critical peaks and dips in the receptance function curve. Source files of Finite Element models are provided in the data. The Finite Element simulation is not only an effective alternative way to estimate the dynamic properties of the rainbow metamaterials, the mode shape analysis, which is unlikely to be achieved with the analytical model, provides direct insights into the underlying vibration mechanism of the rainbow metamaterials.

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*Corresponding author.
E-mail address: menghan1989.123@gmail.com (H. Meng).
1. Data

This article gives the numerical simulation data of dynamic properties of rainbow metamaterials (i.e. resonating elastic metamaterials composed of a P-shaped beams and parallel plate insertions as backbone structures along with the spatially varying cantilever-mass resonators as shown in Fig. 1). The rainbow metamaterial can exhibit single or multifrequency bandgaps depending on whether the two sets of resonators attached to different side walls are symmetric \[1,2\].

The receptance functions and vibration mode shapes within the frequency range 1–500 Hz are simulated. Critical peaks and dips in the receptance function curve is explained with the mode shapes.

Value of the Data

- The data allows the prediction of frequency response functions and modal shapes of the rainbow metamaterials with Finite Element simulation method in Ansys Mechanical APDL
- The numerical simulation data could not only act as an alternative method of modelling the rainbow metamaterial, the modal shapes can reveal the underlying vibration attenuation mechanism that cannot be given out by the presented analytical model \[1,2\], which would aid readers to fully understand the rainbow metamaterials.
- The numerical simulation data can be easily reproduced by researchers in the areas of metamaterials or Finite Element modelling, hence serve as a workbench for the analysis and design of rainbow metamaterials.

2. Experimental design, materials, and methods

In the FE model, the modelling assumptions are as follows: the P-shaped beam and parallel plate insertions are modelled by Shell181 element, the cantilever beams Beam188 element, and the
spatially varying mass element. All the boundaries of the rainbow metamaterial beam are unconstrained.

For the receptance function simulation, a load force $F = 1$ N in Z-direction is exerted on one end of the beam as shown in Fig. 2. Harmonic analysis is subsequently conducted with the ‘full’ method, which solves the simultaneous equation of motion directly. Receptance functions of the metamaterial beam within the frequency range 0–500 Hz are consequently obtained with ratios of predicted displacements at the other end of the beam and the exciting force. With regard to mode shape simulation,
Fig. 4. Mode shapes of the rainbow metamaterial with natural frequencies equal to the critical frequencies marked in Fig. 3.
modal analysis is carried out with ‘Block Lanczos’ method. The physical parameters and geometrical parameters of the rainbow metamaterial are listed in Tables 1 and 2.

The obtained mode shapes could explain the critical points in receptance function curve, which also reveals the vibration mechanism of the rainbow metamaterial. As can be seen from Fig. 4(a), (e), (f) and (h), vibration of the rainbow metamaterial at frequencies $f_2$, $f_3$, $f_4$ and $f_7$ is subjected to mode shapes with dramatically deformed resonators and undeformed backbone structure, namely, the vibration of backbone structure is suppressed at these frequencies, dips therefore appear in the receptance curve as shown in Fig. 3. By contrast, obvious deflection of the backbone structure as well as the resonators could be seen from the mode shapes with natural frequencies $f_1$, $f_5$, $f_6$ and $f_8$, which means the backbone structure vibrates dramatically as the resonators at these frequencies, peaks thus can be seen from Fig. 3 at corresponding frequencies.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dib.2019.104772.

References

[1] H. Meng, D. Chronopoulos, A.T. Fabro, W. Elmadih, I. Maskery, Rainbow metamaterials for broadband multi-frequency vibration attenuation: Numerical analysis and experimental validation, J. Sound Vib. 465 (2020), https://doi.org/10.1016/j.jsv.2019.115005.

[2] Han Meng, Dimitrios Chronopoulos, Adriano T. Fabro, Ian Maskery, Yanyu Chen, Optimal design of rainbow elastic metamaterials, Int. J. Mech. Sci. 165 (2020), https://doi.org/10.1016/j.ijmecsci.2019.105185, 105185.