Low-frequency noise atteniation by acoustic metamaterials

Mechanics of Materials

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Low-frequency noise atteniation by acoustic metamaterials

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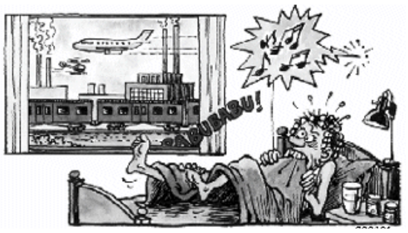
Introduction

80 million people worldwide suffer from unacceptable enviromental noise that cause adverse health effects. The most annoying is low-frequency noise that spreads easily and can be heard for miles. This noise is difficult to absorb; attenuation by an enclosure requires extremely thick walls.



Sources:

- pumps
- compressors
- diesel engines
- aircrafts
- wind turbines
- combustion
- ships etc.

Figure 1: Sources of low-frequency noise.

Acoustic metamaterials are capable of totally attenuating low-frequency noise due to local resonant effect.
Objective: evaluation of geometric and material parameters for acoustic metamaterial to achieve optimal noise attenuation.

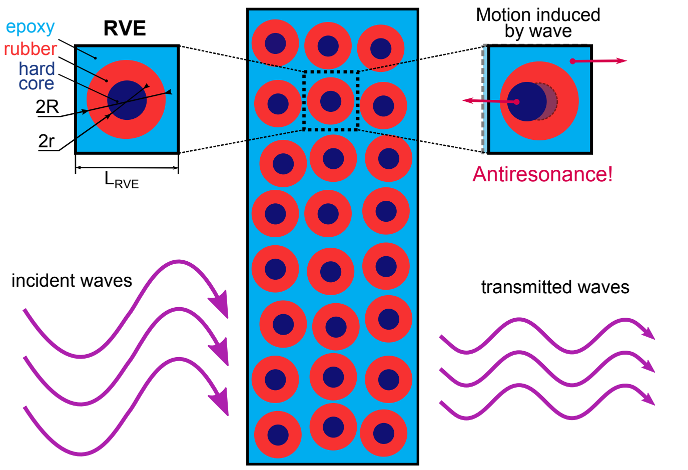


Figure 2: Cross-section of acoustic metamaterial and its basic unit. Local resonance emerges at the frequencies when hard inclusions that act as heavy masses enclosed in soft rubber acting as a weak spring move out-of-phase with the matrix displacement.

Theoretical analysis

The metamaterial properties are studied for material of infinite extent. Plane monochromatic wave of frequency f propagates in the metamaterial with periodically arranged inclusions (cubic lattice). Due to the localized character of resonance, frequencies of affected waves depend mostly on size, material and filling fraction of inclusions, and less on matrix material or arrangement of inclusions.

Lower bound for the frequencies of attentuated waves is governed by eigenfrequencies of inclusions with fixed boundary conditions that can be found analytically. Upper bound is evaluated by taking into account the matrix displacements; this can be performed only numerically.

Numerical results

Fig. 3 shows the dependence of eigenfrequencies of inclusions on r/R for three materials of hard core. The lowest affected sound frequency can be achieved by choosing a heavy core and $r/R \approx 0.3$.

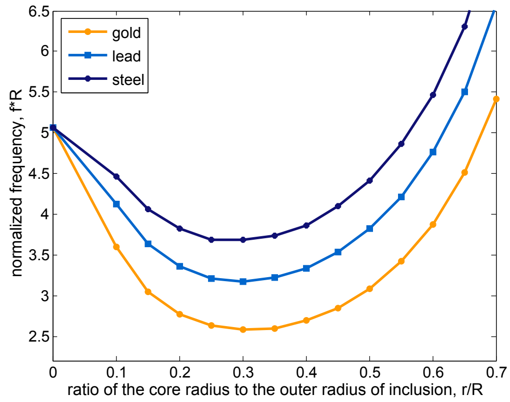


Figure 3: Lower bound for frequencies of attenuated waves as a function of r/R.

Fig. 4 shows the frequency range of affected waves depending on the filling fraction for inclusions with $r/R = 2/3$. The maximum range of frequencies can be attenuated for a dense packing of inclusions.

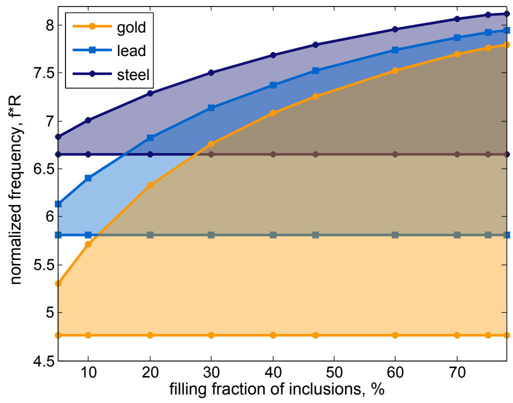


Figure 4: Frequency range of attenuated waves as a function of filling fraction.

Further improvements

The metamaterial chracteristics can be improved by using inclusions of various sizes, but for efficient sound attenuation filling fraction of each type of inclusions has to be no less than about 20%.