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Vibroacoustic metamaterials (VAMM) and acoustic black holes (ABH) New innovative possibilities for the reduction of sound and vibrations.

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Abstract

Conventional primary measures for sound reduction in structures are generally based on two principles: damping (dissipation of sound energy into heat) and insulation (reduction of sound transmission/deflection and reflection of sound waves). Damping coatings/materials or barrier masses/insulation elements can be used for this purpose. However, the effectiveness of these approaches is often limited. In recent years, therefore, innovative technologies have been specifically researched and developed that not only aim to dampen or insulate vibrations but also pursue the goal of directly manipulating the wavelengths and propagation speeds.

Vibroacoustic metamaterials (VAMM) represent one such innovative solution. To achieve this, vibrating resonator structures (see Figure 1 a) are attached in or on a structure. Through the targeted design of these resonator structures, which are usually arranged periodically, VAMM are able to generate negative effective mass properties in frequency ranges above the resonance frequency of the resonator structure. This leads to so-called stop bands, i.e., frequency ranges in which the free propagation of elastic waves is suppressed (see Figure 1 b). Depending on the design of the resonators, the width of the stop band can be set from a few Hz to several hundred Hz. A prerequisite for the creation of the stop band is the periodic arrangement of the resonators on a scale smaller than half the wavelength of the sound to be influenced.

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Figure 1: Vibroacoustic metamaterial (VAMM): a) basic operating principle with VAMM array, b) schematic representation of effectiveness in the frequency range

The application or integration of VAMM in structures opens up new creative design possibilities for the targeted vibroacoustic optimization of structures. For example, innovative noise barriers or cylindrical rocket structures with significantly improved vibroacoustic properties can be designed.

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Figure 2: Vibroacoustic metamaterials (VAMM), flat noise barriers (left) and cylindrical rocket structure (right)

Acoustic black holes (ABH) represent another innovative solution. ABH use targeted geometric modifications of structures to manipulate and absorb wave energy. They are based on the gradual reduction of the cross-section or thickness of a component along the direction of propagation of a wave, see Figure 3 a). These cross-sectional tapers manipulate the waves in their propagation speed so that they move steadily slower in the direction of propagation until the waves come to a complete standstill or the wave energy is dissipated via a small local damping coating. The effect of an ABH occurs at a cut-on frequency (see Figure 3 b) when the wavelengths are small enough to migrate into the ABH.

The effectiveness of ABH depends on the precise design of the geometric taper, with exponential profiles considered particularly advantageous. Optimally designed ABH can reduce structure-borne noise levels by 20 to 25 dB, thus showing slightly lower reduction potential for structure-borne noise levels than VAMM. However, ABH are effective across a broad spectrum from the cut-on frequency and are not limited to a stopband frequency range. Initial applications of ABH can be found in machine components, vehicle structures, and aerospace, for example, for vibration damping on thin-walled plates and beams, in engine blades, etc.

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Figure 3: Acoustic black hole (ABH): a) basic operating principle for one-dimensional wave propagation, b) schematic representation of effectiveness in the frequency range