Nonlinear energy transfer to improve the acoustic black hole effect

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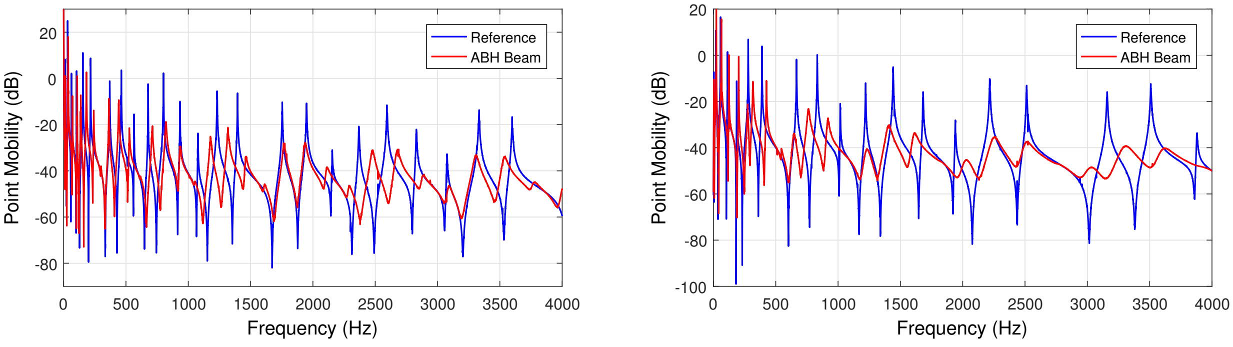
Abstract. Acoustic Black Hole effect (ABH) describes a passive vibration mitigation technique used to damp out the flexural vibrations of thin structures such as beams. It relies on a wedge profile where the thickness is gradually decreasing, so that wave velocities slows down, potentially decaying to zero without reflection. The device generally shows very interesting damping properties in the mid and high-frequency range, however its efficiency in the low-frequency range still remains limited. In this contribution, the inclusion of a nonlinearity as a way to improve the low-frequency performance of an ABH is investigated. Indeed, the nonlinearity may be used as a vector to transfer energy from the low to the high frequency range, where the damping properties are much more significant. Two different mechanisms are tested, based respectively on geometric and contact nonlinearity.

Acoustic black hole

Acoustic Black Hole (ABH) effect is a passive vibration damping technique without added mass. A common implementation is a plate edge where the thickness is locally reduced with a power law profile and covered with a viscoelastic layer. Such mechanisms have been deeply investigated since the pioneering works by Mironov and Krylov [1]. Nowadays, a number of studies show its efficiency thanks to theoretical, numerical and experimental studies [2, 3, 4, 5, 6]. In particular the mitigation properties of a beam with a wedge profile are very important, especially in the mid- and high-frequency range. This is assessed in Fig. 1 where the point mobility (ratio between the vibration velocity and the input exciting force) of a tapered beam (ABH) is compared to that of a uniform beam. Flexural vibrations of the beam are considered, the beam being excited at a single point by a large-band noise excitation. The point mobility of the uniform beam is shown in blue and presents sharp peaks due to the fact that the inner damping is small. The red curve is the point mobility for the ABH, and two different configurations are selected. In Fig. 1(a), the beam is 1.5 m long, with thickness 5 mm. The tapered edge is 20 cm long and the terminal thickness 100 μm. In Fig. 1(b) a shorter beam is considered, with length 1 m and thickness 4 mm. The ABH region is 9 cm long and the terminal thickness 20 μm. In both cases, one can observe that the mobility is severely reduced in the mid and high-frequency range, such that the sharp peaks have been replaced by light bumps, indicating that the damping properties of the beam has been profoundly improved. However, below a certain frequency denoted as the cut-on frequency, the sharp peaks persists and the damping capacity brought by the ABH effect is severely reduced. This cut-on frequency can be roughly estimated around 900 Hz in Fig. 1(a), and 500 Hz in Fig. 1(b).



(a) (b)

Figure 1: Point mobility compared between reference (uniform beam, blue line) and ABH beam (red line). (a) Beam of length 1.5 m, terminal thickness at ABH edge 100 μm. (b) Beam of length 1 m, terminal thickness 20 μm.

Improvement due to nonlinearity

The main idea consists in adding a nonlinear mechanism into the vibrational behaviour in order to transfer energy from the low to the high-frequency range, where it is more efficiently dissipated. Two different nonlinearities are tested. The first case consists in using the geometric nonlinearity, due to large amplitude vibrations. Indeed, in the wedge profile where the thickness is decreasing, the amplitude of the vibrations becomes rapidly of the same order as the thickness, hence exciting geometric nonlinearity. The device can then be adapted by using a longer part of the beam with small residual thickness, in order to excite more easily the wave turbulence regime, able to create an energy flux from the large to the small wavelengths [7, 8]. The second option is to use a unilateral barrier composed of contact points in order to excite a non-smooth nonlinearity.

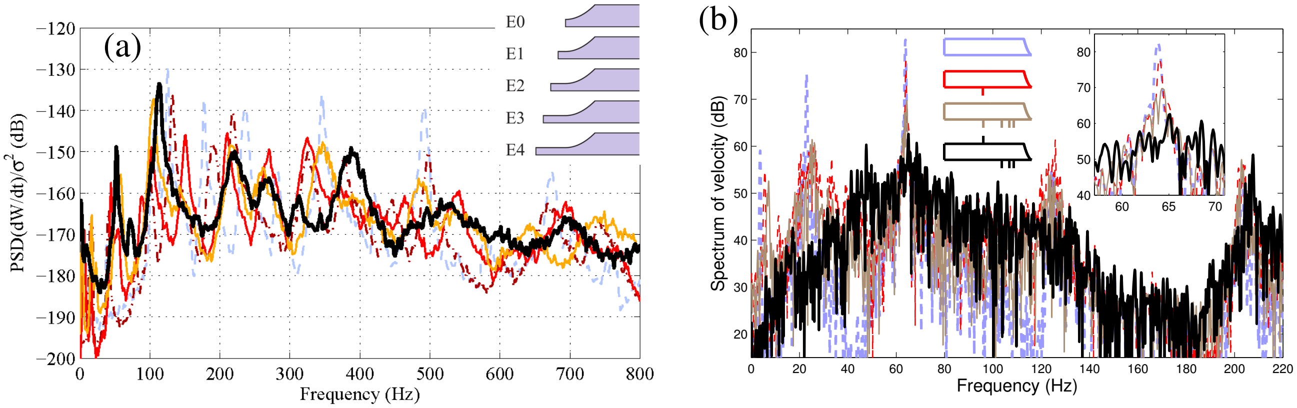


Figure 2: (a) Power spectral density of velocity response to a 100-500 Hz white noise, normalized by the variance of the excitation, in dB. Comparison between 5 different edge termination : E0 (standard ABH with power-law tapered edge) in dashed light blue, E1 (ABH with additional length of constant thickness 50 mm) in brown dash-dotted line, E2 (ABH with added length 100 mm) in red full line, E3 (ABH with added length 150 mm) yellow full line and E4 (added length 200 mm), black thick full line. (b) Velocity spectrum response to a 0-500 Hz white noise compared among different cases of contact condition. Blue line: no contact (standard ABH with power-law tapered edge). Red line: single contact point located at the maximum of eigenmode shape 2. Brown line: 4 unilateral contact points located at the maxima of modes 2-5. Black line: 4 bilateral contact points (up and down the beam).

Fig. 2(a) shows the results obtained for the geometric nonlinearity. The power spectral density of the beam shown in Fig. 1(a), excited with a 100-500 Hz white noise shows that, increasing the length of the beam where the thickness is small and constant, energy leakage is clearly observed so that the global amplitudes of the peaks are decreasing in the low-frequency range. Fig. 2(b) shows the results obtained with the contact nonlinearity, and for the beam which mobility is represented in Fig. 1(b). The excitation is a 0-500 Hz white noise, and three different configurations of contact points are used to show how the energy is transfered. Once again, the main peaks in the low-frequency range are broken (see the zoom on the third mode as inset), so that the global energy in this band is decreasing.

Conclusions

Nonlinear energy transfer provides a practical solution to improve the overall efficacy of ABH performance. Two solutions are tested and compared. More detailed results including quantitative comparisons thanks to dedicated indicators allowing for a complete assessment will be provided. In particular, results show that both methods give good result in terms of improving the performance, however the contact nonlinearity seems to be more efficient as being immediately active. On the other hand, the time scales associated to wave turbulence are longer, so that in the case of geometric nonlinearity, energy transfer takes more time to settle down and pump the energy.

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