Sound vibration damping optimization with application to the design of speakerphone casings

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January 22, 2013

Abstract

Speakerphone technology is used for conference phones, for intercoms, and as a feature in cordless and mobile phones. High quality speakerphones require sophisticated digital signal processing to reduce feedback and to provide echo cancellation, but the result will be better if the device is also acoustically well designed. Special care is needed when the loudspeaker and the microphone are housed in the same cabinet. For instance, damping material such as rubber is then typically deposited at appropriate places. An issue that has received much less attention, however, is how to design the phone casing itself in order to reduce the structural feedback between the loudspeaker and the microphone.

Here, we want to find thickness distributions that prevent transmission of vibrations through the casing without the structure becoming overly compliant for static loads. We use a simplified model of the casing, a $280 \times 70 \times 5$ mm^3 thin plate. One end of the plate is subject to a time-harmonic lateral force, representing the action of the loudspeaker. The other end of the plate is either clamped or subject to a viscous damping boundary condition, simulating a vibration isolation pad located between the plate and the supporting table. Assuming that a microphone is mounted on the plate, we wish to find a thickness distribution of the plate that minimizes the lateral vibrations in the area where the microphone is located. Lateral deflections of this plate are well modeled by the dynamic variable-thickness Euler–Bernoulli beam equation, as verified against 3D structural mechanics solutions from a commercial software (COMSOL Multiphysics 4.2).

The thickness distribution of the beam model is optimized using a Sequential Quadratic Programming algorithm (Matlab's `fmincon`). The objective function is the amplitude-square of the vibrations in the selected region of the beam. Upper bounds on the weight as well as lower and upper bounds on the beam thickness are imposed. We also impose an upper bound on the static compliance.

A broadband optimization over 50 frequencies, evenly distributed in the 300–3400 Hz range, reduces the vibration by around 5 dB on average throughout the frequency range. The main mechanism for vibration reduction seems to be to locally thicken the plate around both the loudspeaker and microphone positions. When targeting only the higher end of the above frequency range, it is possible to achieve more dramatic results. Vibration reductions of 20 dB and more can be achieved in the 2300–2800 Hz region. The mechanism behind the reduction in this case seems to be more complicated. In addition to the thickening of the beam around the source and receiver locations, the results also suggest that a band-gap phenomenon occurs, similarly as for phononic band gap materials; in the optimal thickness distribution appears quasi-periodic shapes at scales roughly equal to the wavelength of the vibrations in this frequency range. To verify the results, the best-performing optimal shape for the clamped case was imported into the 3D structural model, and the resulting forced vibration response agreed well with the the beam-model computations.