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Shape optimization for electro-acoustic-mechanical micro systems

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The design of audio related micro-electro-mechanical-systems (MEMS) such as transducers, hearing aid receivers/transmitters, sensors, mobile phone components, etc. is becoming more and more difficult due to the increasing demands for additional functionality, decreasing size of the components and the desire for lower power consumption. This makes an already complicated and multi physical engineering design task ever more complicated. Thus, a fundamental need for new insight and design methodologies are needed, and one such tool that can provide insight into both physics and geometric layout is systematic structural optimization.

The physics governing the investigated design problem includes the coupling between mechanical stresses and the intensity of an electric field through Maxwell's stress tensor. This relation dictates that the deformation of the mechanical structures, which also acts as electrodes, influences the intensity of the electric field. Hence, the modelling of the electric field must be conducted in the deformed configuration, which even for very small deformations can lead to a substantial change in electric field. It is worth noting that the interaction between elasticity and electromagnetics only takes place on the interface between the conductor and insulator. This fact is especially important when choosing the structural optimization tool to be applied later. Having determined the deformed equilibrium of the conductor/structure makes it possible to evaluate the acoustic-mechanical coupling and subsequent frequency response of the time-harmonic vibroacoustic system. Again, we emphasize that the acoustic-mechanical interaction occurs on the interface between the mechanical structure and the surrounding fluid (air). To summarize, the numerical modelling consists of first solving a static, non-linear mechanical-electrical system. This is followed by a linearization of the dynamic equations about the deformed equilibrium, which is then perturbed by a mechanical, time-harmonic load to obtain the frequency response.

The modelling - and subsequent optimization - problem can be investigated using several numerical approaches where the most interesting for structural optimization are 1) a monolithic PDE formulation with varying material parameters to be used with topology optimization and 2) immersed boundary methods such as CutFEM or xFEM to be used for generalized shape optimization. Due to the highly localized coupling at the interface, the desired resonance phenomena under operation and the non-linearity of the model problem, the authors have chosen to apply the CutFEM approach together with shape optimization. The optimization problem is solved by gradient based methods, i.e. the Method of Moving Asymptotes, and we apply adjoint analysis to obtain the sensitivities. The viability of the design methodology is demonstrated on problems in which the goal is to maximize the acoustic output, e.g. the sound-pressure-level, by modifying the shape of the mechanical structure and electrodes, subject to different input voltages and harmonic, mechanical loads.