A preliminary study of an isodynamic transducer for use as active acoustic materials

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Introduction

An active material with variable acoustic properties is an electroacoustic transducer, behaving both as captor and actuator within an acoustic field, and the acoustic impedance of which can be controlled. One can then modify its properties, such as the absorption coefficient α, to change the acoustic behaviour of a room. We choose in the following to illustrate this concept with electrodynamic transducers (moving coil and isodynamic transducers).

The concept of active materials

Acoustic impedance monitoring

The acoustic impedance of the transducer is controlled via a combination of pressure and acoustic velocity feedback [1] (which is obtained with an electric impedance bridge setup, see Figure 1). The acoustic impedance is then a simple function of Γ_2/Γ_1 ratio [2], where Γ_1 and Γ_2 are the gains for pressure and for velocity feedbacks. Setting Γ_2/Γ_1 is then equivalent to setting absorption coefficient α.

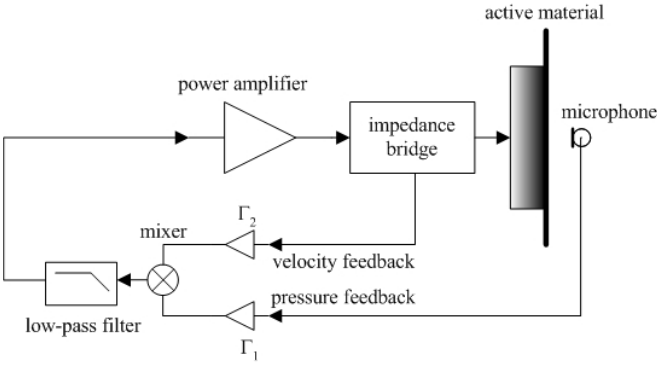

Figure 1: principle of active material

The most critical parameters for optimizing this control are Bl^2/R_e (where Bl is the transducer's force factor, R_e the electric resistance of the moving coil [3]), which governs the bandwidth of the control and allows low feedback gains and less use of energy, and also m, moving mass of the diaphragm, that limits the performances of the control at high frequencies [4].

Stability of the control

The open-loop gain of the control is a simple function of the electroacoustic parameters of the transducer. The radiation impedance Z_r, as well as the electric inductance L_e of the coil, are the most limiting parameters in terms of stability (instability occurring in particular at very high frequencies).

Wall of active materials

It has been shown that one active material (also called active cell), doesn't significantly affect the behaviour of the other active cells in the wall. Especially in terms of stability, the change of radiation conditions in an active panel doesn't lower much the stability of each cell [5].

Experimental results with an active wall

A panel using 4x4 Audax HT240M0 electrodynamic loudspeakers has been build, each cell's own acoustic impedance being controlled independently. Figure 2 shows absorption coefficients measured (derived from the acoustic impedance measured by pressure and velocity captions, respectively with a microphone and a laser velocimeter), on 4 loudspeakers along one row of the wall, and in two cases of control: on left chart, Γ_2/Γ_1 is set for maximum absorption, while on right chart Γ_2/Γ_1 is set for α=-2 (i.e. "super-reflection"). Both were obtained with good stability conditions [4]. One can see that, in both cases, the control is more effective around the transducer's resonance frequency (f_s=150 Hz). The dotted curve corresponds to one passive material, i.e. without control (reaction of the free loudspeaker's diaphragm to the acoustic field).

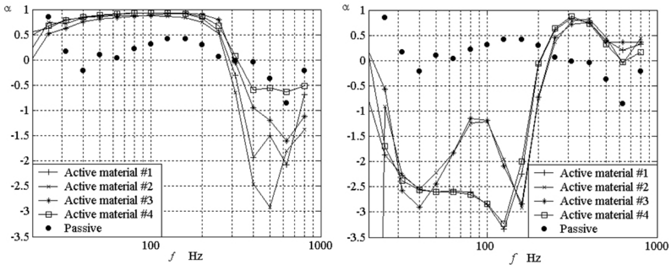

Figure 2: absorption coefficients obtained with 4 active cells in a wall, for 2 settings (on the left: α=1, on the right: α=-2)

The active isodynamic material

Introduction and principle of transduction

A first optimization study led us to investigate the use of isodynamic transducers as active material. The main favourable parameters are its low moving mass m, the very low value of inductance L_e (compared to R_e at high frequencies), and the possibility to reach high Bl^2/R_e (Bl of about 1T.m and R_e=13Ω for a 15 m electric conductor [4]). Another interesting feature is a low manufacturing cost with use of rubber magnets.

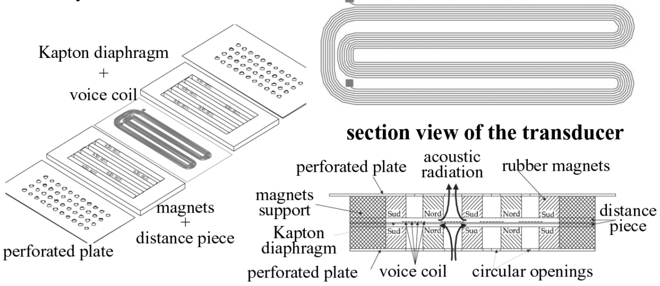

Figure 3: description of the isodynamic transducer

An isodynamic transducer is composed of a slim and light polymer film (such as Kapton®), on which an electrical circuit (aluminium or copper) is deposited as shown on Figure 3 (about 20 μm thick), the whole static mass being mostly due to the circuit. The transduction is effected by two rows of rubber magnets, inducing “isodynamic” displacements upon the diaphragm. The diaphragm is positioned between the two magnets rows with distance pieces, allowing it to vibrate along the gap width *e* [6].

Modelling

A finite elements model of the isodynamic transducer has been designed and computed, in order to predict its behaviour as an active material. Input data are the size of the diaphragm, number and dimensions of tracks, metal type of conductor, number of magnets, and gap width. The most critical point in the modelling has been to take the acoustic effects of air mass in the gap between the magnets rows into account. With hundreds of μm width, an additional acoustic mass has been pointed out by electric impedance measurements, which seems to dominate the mechanical behaviour of the whole diaphragm, and then lowers the performances of the active material (since *m* is a critical parameter for this active impedance control). Though, the thinner this space, the higher the transducer’s force factor.

Simulation results

We chose to present results obtained by simulating the behaviour of an isodynamic transducer, made of a 25μm thick Kapton® diaphragm (175 mm long by 85 mm large), with 5 strips of 16 copper tracks deposited on it (tracks sections of 600x36 μm^2). The whole is put between two rows of 5 rubber magnet sticks (10x10 mm^2 section, 175 mm long), with 12 mm between each stick.

Figure 4 illustrates the influence of the air in the space between the two rows of magnets on the performance of the control. Three cases of control have been simulated: active absorption (α set to 1), active super-reflection (α set to -2), and the passive set-up (no control). In a first calculation (left chart), the equivalent acoustic mass of air in the 1mm wide gap is not taken into account, and in the second case (chart on the right), it has been calculated (corresponding to an additional mass of about 8.1 g).

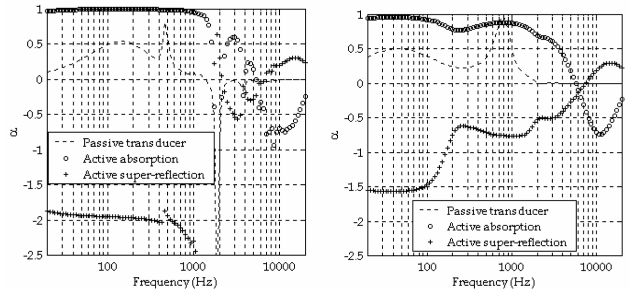

Figure 4 : absorption coefficients obtained by way of simulation for an isodynamic active material (left: acoustic mass not taken into account; right: considering the equivalent acoustic mass for *e*=1mm)

We can see that the performance of the control is lowered by this additional mass, in the high frequencies, and the values of α are not the same in the two cases, for the same feedback gains. If the influence of the air on the acoustic mass of the transducer can be reduced (by designing acoustic circuits inside the transducer), α~0 or α~-2 could be reached over, at least, 2 frequency decades (from 20 Hz to 2000 Hz), depending on the nature and size of the diaphragm.

Experimental results and conclusions

A prototype has been built, with 16 copper tracks ($600x36\mu m^2$ section) i.e. a moving mass of m=2.7g and electric resistance R_e=13Ω. Two gap sizes (e=1.6mm for an estimated force factor of Bl=4.3T.m, and e=4mm for an estimated force factor of Bl=1T.m) have been tested. Only active absorption has been tested (see Figure 5).

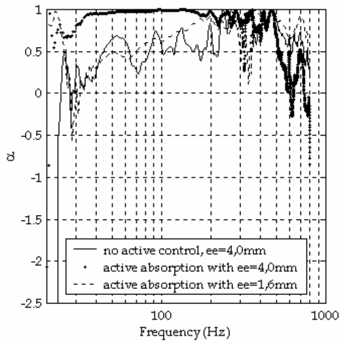

Figure 5: experimental results obtained on active absorption (α set to 1), with two air gap widths (e=4mm, dotted line e=1.6mm)

One can see that for too low air gap width, poor active absorption has been obtained. For *e*=4mm though, even if force factor decreases as *e* increases, the control is better, with α~1 over 1.5 decades. The behaviour of the control tends to be the one predicted in the simulations.

Conclusions

We can see that, if it is possible to ensure low gap width *e*, while reducing the influence of the acoustic mass, better active control would be obtained on isodynamic materials, in the absorption case as well as in the super-reflective case. By optimizing the mechanical components of the diaphragm, and keeping low cost objectives in mind, active materials are a promising concept for hall acoustics active control.

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