AN INNOVATIVE APPROACH TO SPATIAL FILTERING WITH PIEZOELECTRIC FILMS FOR VIBROACOUSTIC APPLICATIONS

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ABSTRACT

A new porous electrode concept is introduced, which allows to construct two-dimensional spatial filters through the tailoring of the effective piezoelectric coefficients. Preliminary validation tests of the porous electrode are presented on a cantilever beam.

1. INTRODUCTION

There are two broad ways to achieve spatial filtering with piezoelectric films: (i) arrays of discrete sensors and (ii) continuous distributed sensors. Discrete array sensors (Fig.1), if wired with independent conditioning electronics, are reconfigurable, but they suffer from spatial aliasing when sensing structural modes with wavelength comparable to the spacing between the sensors in the array. Spatial aliasing usually produces a sharp increase in the open-loop FRF in the roll-off region (Fig.2), which brings strong limitations for applications in structural control (a good rule for sensor selection for structural control applications is that their behaviour should be guaranteed at least one decade above the bandwidth of the control system).

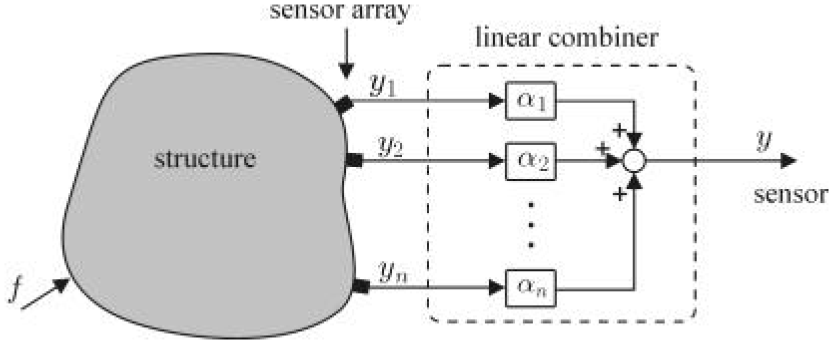

Figure 1: Representation of the spatial filter using *n* discrete sensors.

The modal filtering of one-dimensional structures with continuous PVDF films can be traced to Burke and Hubbard (1987) and Lee and Moon (1990). It is achieved by tailoring the width of the electrode (and possibly reversing the polarity). Although the spatial filtering of plates and shells with two-dimensional PVDF films has been suggested (Lee and Moon, 1990), it has never been implemented for lack of capability of continuously shaping the piezoelectric properties of the sensor material. This paper proposes a way to turn around this difficulty by proper electrode design, and preliminary validation tests are presented.

2. NOVEL ELECTRODE CONCEPT

The two-dimensional theory of spatial filtering does not work because it assumes that the piezoelectric properties can be varied spatially [$e_{31}(x, y)$] and this cannot be done in practice (the material can be either polarized or not). Here, we take a different perspective, and exploit the fact that the part of the piezoelectric film which is not covered by an electrode does not participate to the electric charge generation. Thus, if one can produce a "porous" electrode with a specified porosity (Fig.3), it will be equivalent to tailoring the piezoelectric properties.

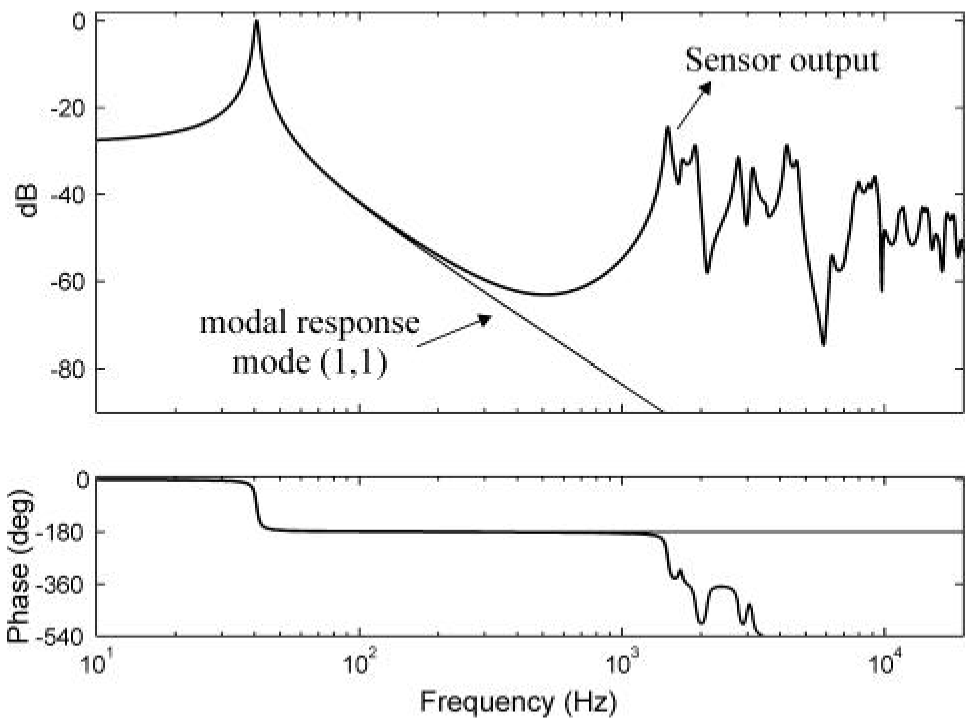

Figure 2: Example of modal filter achieved with a discrete array sensor (rectangular plate with an array of 4 × 8 piezoelectric patches). The agreement between the modal response and the sensor output is good at low frequency; the discrepancy at higher frequency is due to spatial aliasing.

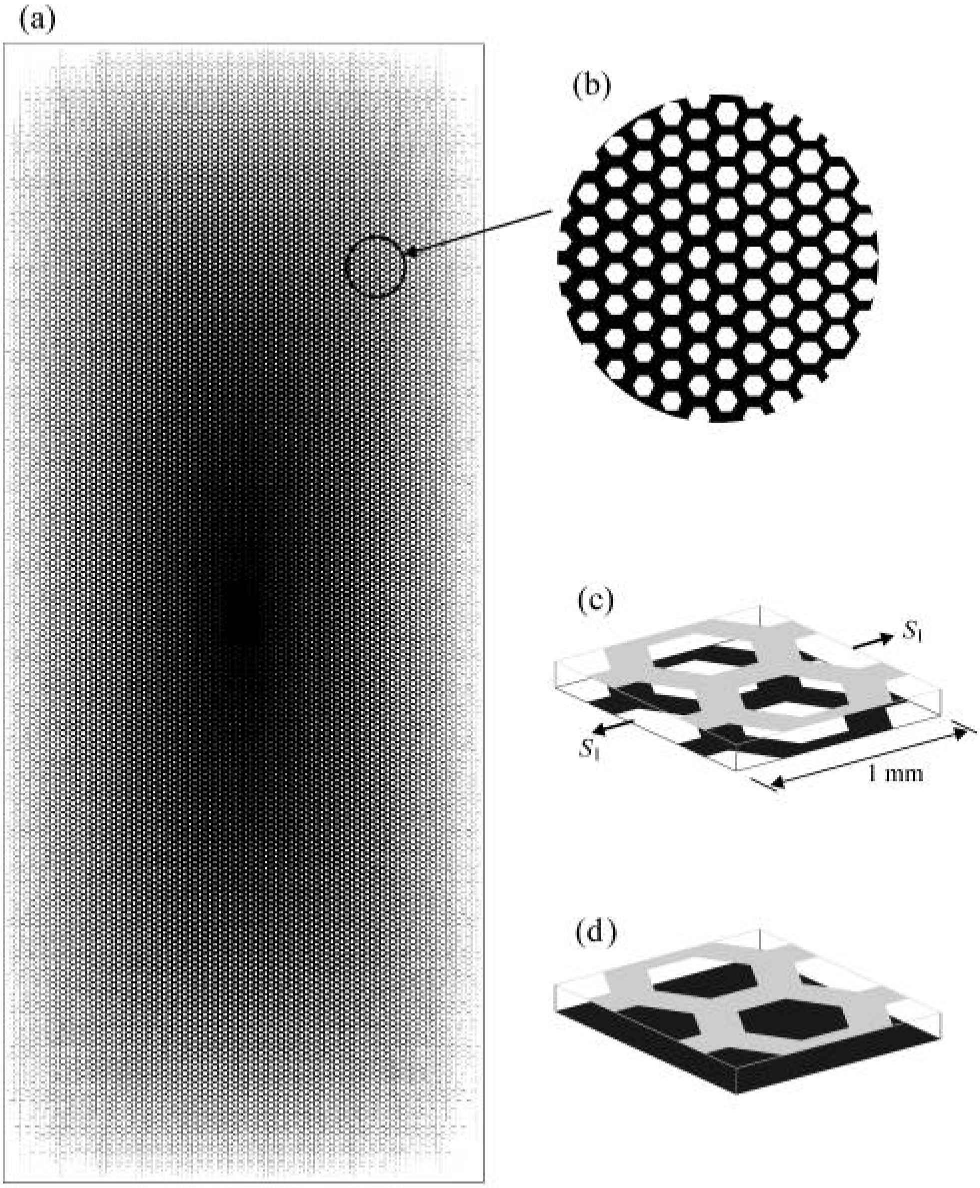

Figure 3: (a) Porous electrode, (b) detail of the motif with variable porosity, (c) double sided motif (fraction of electrode area = 50 %), (d) single sided motif (the other electrode is continuous).

Consider a piezoelectric film polarized in the direction normal to ts plane and covered with electrodes Ω as in Fig.4. According to the two-dimensional theory of piezoelectric films, if a sample is subject to a plane strain field aligned on the orthotropy axes of the material, and if the electrodes are connected to a charge amplifier which cancels the electric field across the piezoelectric film, the electric charge produced on the electrodes is

$$Q = \iint_{\Omega} (e_{31}S_1 + e_{32}S_2)\, d\Omega \qquad (1)$$

where S_1 and S_2 are the strain components along the orthotropy axes in the mid-plane of the film, and e_{31} and e_{32} are the piezoelectric constants of the material. The integral extends over the area of the electrode or, more precisely, the area Ω over which the two electrodes overlap, where the electrical field is zero. According to Equ. (1) changing the local electrode density ($d\Omega$) is equivalent to changing the piezoelectric coefficients e_{31} and e_{32} in the same ratio. Since Ω refers to the area where the two electrodes overlap, the motif may be etched on the electrodes on both sides of the piezo film (Fig.3.c) or only on one side, with a continuous electrode on the other side (Fig.3.d), which seems technologically simpler, because the two electrodes do not have to be aligned precisely on top of each other.

Equation (1) assumes that the size of the electrode is much larger than its thickness. However, when the motif of the electrode becomes small, tridimensional (edge) effects start to appear and the relationship between the electrode porosity and the equivalent piezoelectric property is no longer linear. The exact relationship between the porosity and the equivalent piezoelectric coefficients can be explored with a tridimensional finite element analysis software (Piefort, 2001). Figure 5 shows the relationship between the effective piezoelectric coefficients $e_{31} = e_{32}$ of an isotropic PVDF (copolymer) and the fraction of electrode area for the two electrode configurations of Fig.3.(c) and (d) and two sample thickness (10 µm and 100 µm); note that, for a very thin sensor, the two electrode configurations produce the same result and the relationship is almost linear.

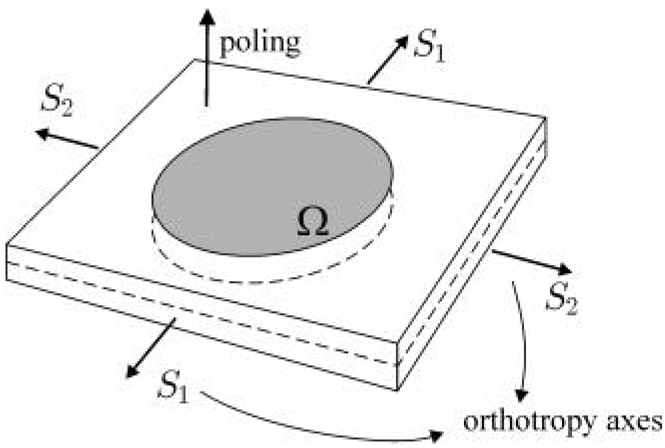

Figure 4: Sample of piezoelectric film polarized in the direction normal to its plane and subjected to plane strains along the orthotropy axes.

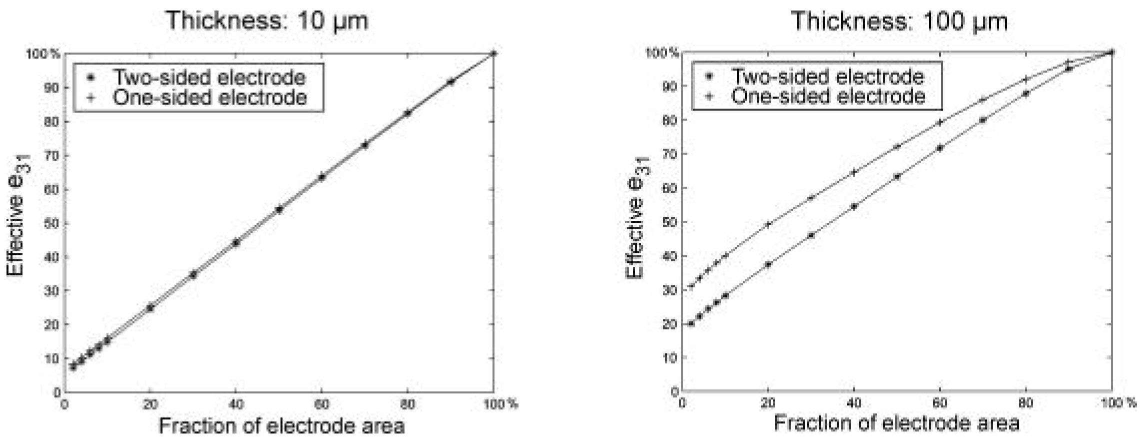

Figure 5: Effective piezoelectric coefficient vs. fraction of electrode area.

3. VALIDATION TEST

To the authors' knowledge, this concept of "porous" electrode is new (Preumont, 2002). This section reports on the preliminary test program aiming at validating the new concept.

Figure 6 shows the experimental set-up. Two cantilever beams made of glass of 240 mm × 27 mm × 1.83 mm are equipped on one side with a PZT actuator and on the opposite side with an isotropic PVDF (copolymer) sensor with a shaped electrode. In one case, the electrode profile matches the modal filter of the beam theory (Lee and Moon, 1990); in the other case, the same axial variation of the piezoelectric properties is achieved with the porous design described in the previous section. However, to guarantee the continuity of the honeycomb electrode during the manufacturing process, the width of the electrode is constrained to be larger than 0.5 mm; this explains why the electrode design is tapered near the free end of the sample.

Figure 7 compares the FRF between the PZT actuator and the PVDF sensor for the two electrode designs. The two curves are remarkably close, although significantly different from the ideal modal filter; this difference is partly due to the fact that the PVDF material is isotropic ($e_{31} = e_{32}$).

Further tests are under way to validate the new electrode design on rectangular plates.

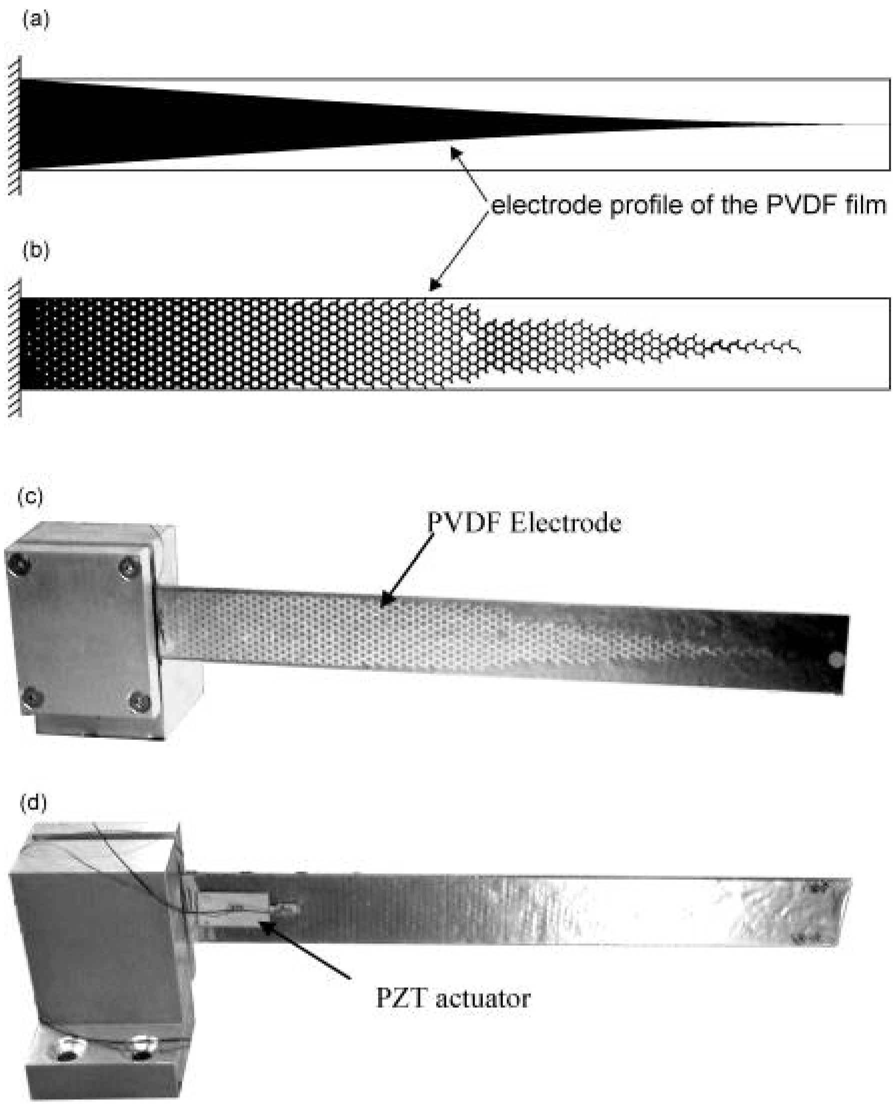

Figure 6: Experimental set-up for the honeycomb electrode validation.

4. CONCLUSIONS

A new porous distributed electrode concept has been introduced which allows to tailor the effective piezoelectric coefficients in two dimensions. Its use as modal filter has been discussed. Preliminary validation tests of the porous electrode design have been presented on a cantilever beam. The application of this concept to volume velocity sensing is discussed in Preumont (2002, b).

ACKNOWLEDGEMENTS

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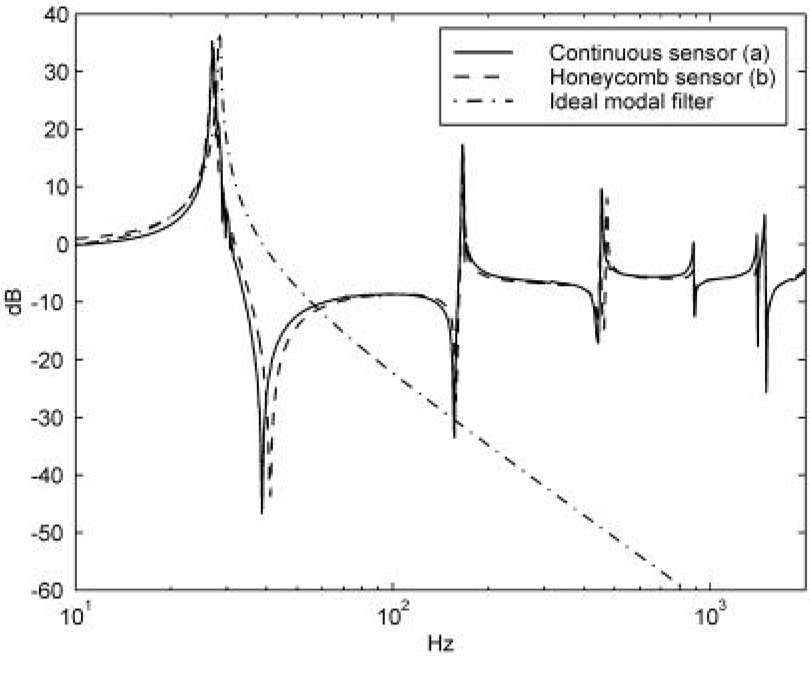

Figure 7: Comparison between the measured FRF of the continuous and honeycomb sensors with the FRF of the analytical beam model.