

## Study of a dome shaped PVDF loudspeaker

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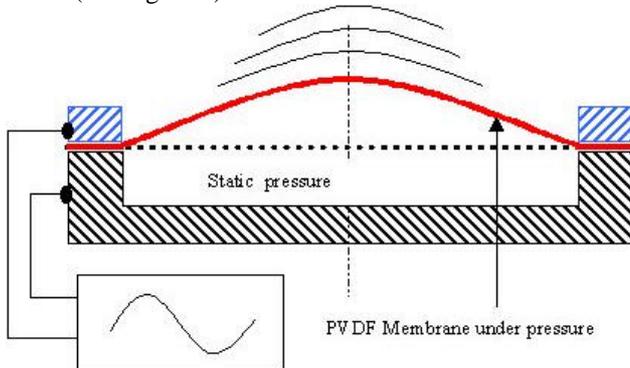
### Introduction

PVDF loudspeakers are used for some applications in audio [1] and could be used for applications in active control where light structures are needed, for example in aeronautics [2]. For all these applications, it is necessary to be able to predict the acoustic response of such systems in order to help the designer. Some papers propose models for calculating the acoustic pressure radiated by these loudspeakers [3].

The paper focuses on a dome shaped PVDF loudspeaker. The aim of the work is to study the accuracy of models proposed in literature. First part of the study focuses on the static behaviour of the speaker. The static deformation is calculated using models found in literature and is compared to this obtained by means of numerical and experimental methods. Second part focuses on the dynamic behaviour of the speaker. At first, analytical models found in the literature are used for predicting the acoustic pressure radiated. Secondly, a finite elements model is used for calculating the acoustic pressure radiated in the near field of the speaker. Finally, an experiment is conducted for measuring the pressure response of the speaker

### Description of the loudspeaker

The PVDF loudspeaker consists of a circular PVDF thin film, clamped around, dome shaped by means of a static pressure which is applied at the back. A time variable voltage applied between the two faces of the film enables to produce a acoustic pressure by means of the piezoelectric effect (see Figure 1).



**Figure 1:** PVDF loudspeaker principle. The dome shape is obtained by means of a static back pressure. The radiated acoustic pressure is produced by a time variable voltage.

### Static study

#### Analytical models

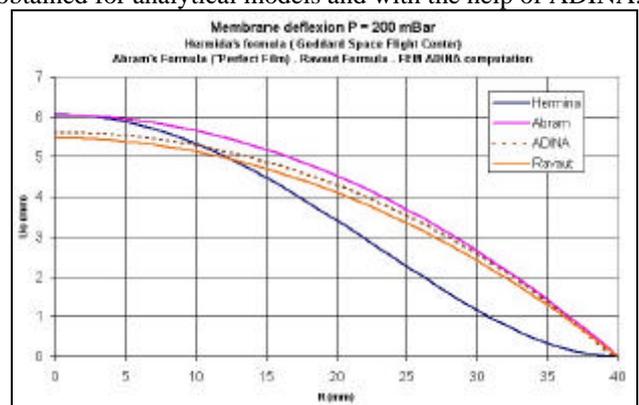
The aim of this section is to validate analytical models giving the static shape of the membrane as a function of the back static pressure. Different models assuming that the membrane shape is a paraboloid are proposed in the literature (Abram [4], Hermida [5]). Ravaut [6] expresses the membrane displacement as a infinite serie depending on the adimensional radius. Using these work, it is possible to derive a general expression of the membrane displacement  $z(r)$  :

$$z(r) = \lambda R \sqrt[3]{\frac{P_s R}{E_{pe} h_{pe}}} \left[ 1 - \left(\frac{r}{R}\right)^2 \right] \tag{1}$$

where  $\lambda$  is a coefficient depending on the Poisson coefficient of the piezoelectric material  $\nu_{pe}$  and on the model which is used.  $R$  is the radius of the membrane,  $P_s$  is the static pressure,  $E_{pe}$  is the Young modulus and  $h_{pe}$  is the thickness of the film.

#### Finite elements

In order to validate the models presented above, the static deflection of the membrane is calculated by means of a finite elements method (ADINA). Figure 2 presents results obtained for analytical models and with the help of ADINA.

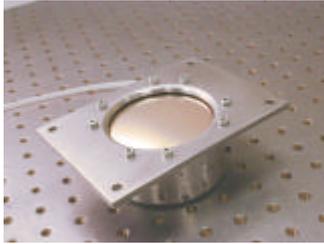


**Figure 2:** static deflection of a PVDF membrane (radius 40 mm, thickness 25 microns) obtained by means of analytical models (full line) and finite elements method (dotted line). Back pressure = 200 mBar.

These results show that the simplified Ravaut model, used in this work, enables to predict the static deflection of the membrane with a relative error of 2%.

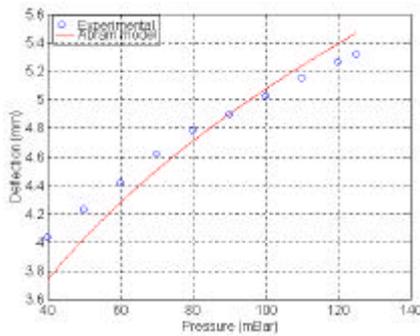
### Experimental study

A loudspeaker prototype has been developed in order to validate the models presented above (see Figure 3).



**Figure 3:** View of the PVDF loudspeaker prototype

Figure 4 shows the measured static deflection and the Abram model result using a adjusted Young modulus for the PVDF (2.7. GPa instead of 3.2 GPa). The error between the two deflections is about 6 %.



**Figure 4:** deflection of the centre of a PVDF membrane (radius 40 mm, thickness 25 microns) as a function of back static pressure. Experiment : circles, Abram model : full line.

### Dynamic study

This part of the work concerns the study of the acoustic pressure frequency response of the loudspeaker. As for the previous section, results deduced from existing models are compared with results obtained with a finite elements method and with experimental results.

### Analytical model

The analytical model used in this work has been proposed by Garner and Holden [3]. The dynamic membrane displacement  $\xi(r)$  is calculated assuming that there is no coupling between the membrane and the air :

$$\xi(r) = \frac{2V_3 dE_{pe}}{k^2 \rho (1 - \nu_{pe}) T_{pe}} \left[ 1 - \frac{J_0(kr)}{J_0(kR)} \right] \quad (2)$$

$V_3$  is the applied voltage between the faces of the film,  $d$  is the piezoelectric constant ( $d = d_{31} = d_{32}$  for bioriented film),  $k$  is the wave number of the membrane

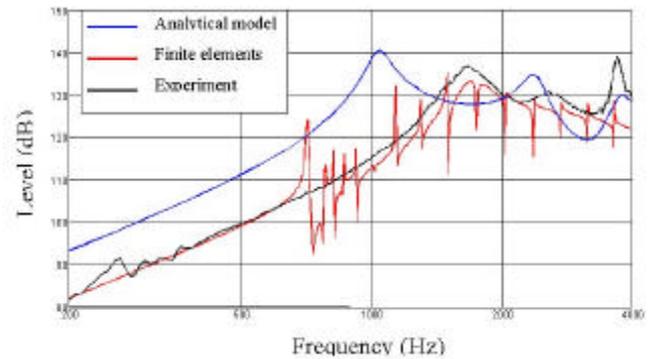
$$k^2 = \omega^2 \frac{\mu_{pe}}{T_{pe}}, \quad (3)$$

where  $\mu_{pe}$  is the surface density of the film and  $T_{pe}$  the tension of the membrane.  $\rho$  is the curvature radius of the dome depending on the back static pressure and  $J_0$  is the

Bessel function of first kind and order zero. Using the dynamic displacement  $\xi(r)$ , the Rayleigh integral enables to calculate the acoustic pressure radiated by the loudspeaker.

### Results

The acoustic pressure radiated by the loudspeaker is calculated by means of the analytical model and by means of a finite element method (ATILA®). The pressure delivered by the prototype is also measured. Figure 5 shows the acoustic pressure radiated by the PVDF loudspeaker.



**Figure 5:** acoustic pressure radiated by the PVDF loudspeaker at 5 mm from the dome centre for a 10 V rms voltage. Back pressure = 50 mBar, Film thickness = 25 microns.

### Conclusion

The study of a PVDF dome shape loudspeaker shows that analytical models can predict the static deflection of a PVDF membrane. However, further experiments should be conducted in order to validate these models. The dynamic study shows that analytical models have to be improved in order to fit the experimental and numerical results. Future work will consist in taking into account the coupling between the membrane and the air.

### References

- [1] Tamura et al, Electroacoustic transducers with piezoelectric high polymer films, *JAES* **23** (1975), ??-??
- [2] Guigou C., Fuller C.R., Control of aircraft interior broadband noise with foam-pvdf smart skin, *J. of Sound and Vib.*, **220-3** (1999), 541-557.
- [3] Garner Geoffrey M. and Holden Anthony J. , Tone ringer using PVDF piezoelectric film, *JASA* **83** (1988), 1940-1945.
- [4] Abram R.A. , the theory of a piezoelectric plastic film transducer for earphones, *J. Phys. D : Appl. Phys.* **13** (1980), 201-207.
- [5] Hermina A, Deflection of a circular membrane under differential pressure  
URL:<http://www.nasatech.com/Briefs/May98/GSC13783.html>
- [6] Ravaut Y, Bouzidi R., Caractérisation du comportement d'une membrane circulaire bloquée sur sa circonférence soumise à une pression uniforme, XV<sup>ème</sup> congrès Français de Mécanique, Nancy 3-7 septembre 2001.