# CHARACTERIZATION AND FIRST APPLICATION OF A THIN-FILM ELECTRET UNSTEADY PRESSURE MEASUREMENT TECHNIQUE

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## ABSTRACT

A new thin-film electret unsteady pressure measurement technique for application in turbomachine aerodynamical experiments is under investigation. The technique is based on a layered sensor comprising a permanently polarized foil in the center. Changes in foil thickness due to variation in pressure result in a potential difference, which is used as measurement signal.

The investigated technique presents a cost attractive alternative for unsteady pressure measurement instrumentation. Low signal levels however put severe requirements to acquisition and the treatment of the signals, especially when reducing the sensor area.

First measurements have been performed with a 2.5x2.5mm sensor. The signals have been correlated to Kulite data and good agreement has been found. A characterization of the technique as well a description of the first tests in relevant flow is presented in the paper.

## INTRODUCTION

Unsteady pressure plays an important role in turbomachinery aerodynamics and it is therefore of vital interest to the experimentalist to have a reliable and affordable measurement technique. Forced response is one of the phenomena where unsteady pressure measurements find application such as to determine the unsteady blade loading that leads to the forcing of a structure. A major source of excitation comes thereby from adjacent blade rows at a rather high frequency of several kHz. On the other hand the unsteady aerodynamics due to blade oscillation, which typically could lead to flutter, is another area in which unsteady pressure measurements are of interest. This phenomenon typically occurs in the lower kHz range but due to the small magnitude of aerodynamic damping requires a suitable resolution of the measurement technique.

Traditionally piezo-resistive techniques such as used in Kulite sensors are employed for measuring unsteady pressure. These techniques provide a voltage that is calibrated for pressure and feature favorable resolution and high frequency response in the order of hundreds of kHz. A drawback of this type of sensor is relatively high costs per data point taking into account sensor cost and instrumentation. Recently optical unsteady pressure measurement techniques (PSP) have been presented as alternative. This technique is especially attractive as a large continuous area can be covered at one shot, however as there are diffusion processes involved featuring rather larg time-scales a successful application in the order of several hundred Hz has not been shown to date.

The present thin-film electret technique presents an alternative as it features the potential to achieve most of the aforementioned requirements [1]. A typical sensor comprises a permanently polarized foil (the so-called electret foil) and two electrodes on either side. Changes in electret foil thickness lead consequently to a change in potential on the electrodes, which can be measured using a voltage measurement device and correlated to the change in pressure. One of the major differences of this technique from the ones described above is that it only allows the direct measurement of changes in pressure, thus it provides only information on the unsteady pressure. Furthermore the changes in potential are proportional to the sensor size, which leads to small signal levels for small sensor sizes. Low costs and simple application as well as possibilities for arrangement of the sensors in matrices make this technique very promising for certain range of unsteady pressure measurements.

The investigated sensors have been calibrated using a dynamic pressure calibration technique [2]. A theoretical model has been adapted to calibration data such as to characterize the sensors over a range of frequencies and sensor sizes down to 1x1mm. Thereafter a sensor has been tested in realistic unsteady flow in one of the wind tunnels of the Chair of Heat and Power Technology at KTH [3]. Kulite measurements have been preformed for validation purposes.

## DECSRIPTION OF SENSOR

The investigated sensors comprise a permanently polarized and porous foil featuring an electrode on either side. The material of the sensor foil is foiled polymer with flat voids as shown in Fig. 1. Typical dimensions of the voids are 30…100 µm in diameter and 1...5 µm in height. Charge separation in the voids is achieved at elevated temperatures and exposure to strong electric field. Given a high resistivity of the film the charge strength remain farly constant over time and features typical half-life of the order of 100 years [1].

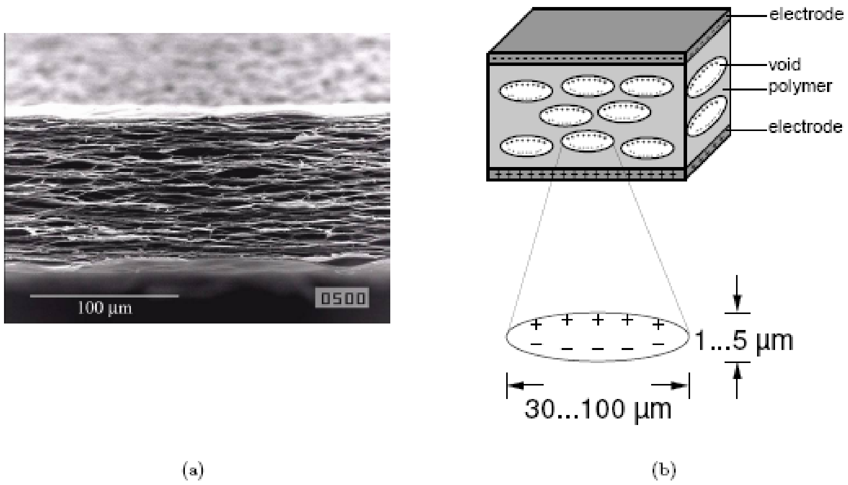



**Fig. 1: Electret sensor film; a) REM picture, b) schematic of internal structure**

Given the porosity of the film the thickness changes under pressure and induces a change in electric field inside the film This change in turn leads to an instantaneous generation of mirror charges on the electrodes connected to the film surfaces. For small compressions the change in film thickness is proportional to the generated charge [1].

The sensors investigated in the present paper have been built in-house using a piece of electret foil (provided by the University of Kupoio, Olkkonen) and two electrodes coated with a transversally conducting layer (3M, type 1181). Different sensor sizes have been tested. For the characterization as well as the application presented herein a sensor sized 2.5x2.5mm has been investigated. Although this sensor size seems rather large it has been chosen such as to have an favorable signal strength for this part of the work.

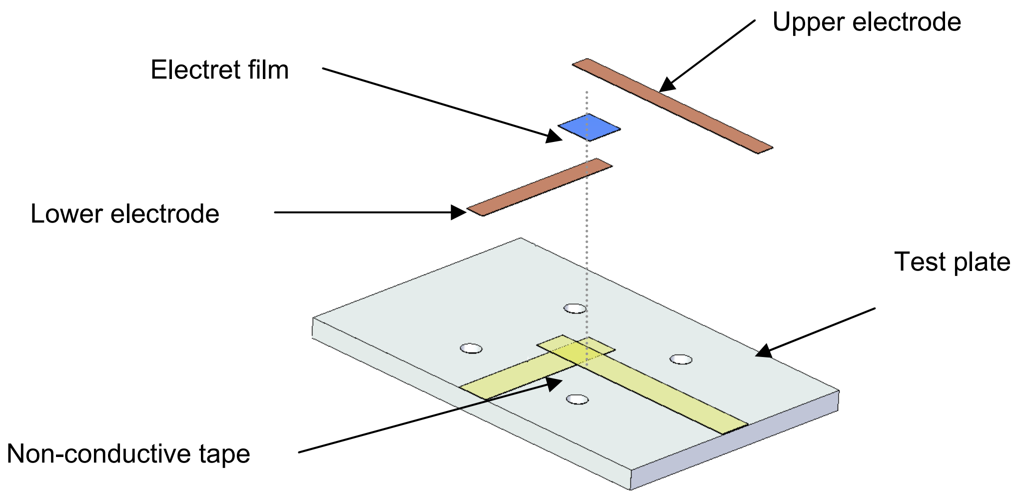



**Fig. 2: Schematic of sensor build-up [4]**

**TEST SETUP**

The characterization of the sensor is done using an in-house unsteady pressure calibration system [2]. A reference cavity is thereby placed fixed over the sensor to be investigated. This cavity contains also flush-mounted Kulite sensor for reference purposes and is supplied by an unsteady pressure signal from a pressure pulse generator. Pulse amplitude and frequency can thereby be set independently. A digital high-speed data acquisition system (KT8000) is employed for measuring the sensor signals. The system provides 32 channels featuring programmable pre-amplifiers, low-pass filters and 14bit AD conversion at maximum parallel sampling rate of 200kHz. The signals from the sensor to calibrate (i.e. the thin-film electret sensor) and the reference sensor (Kulite sensor) are acquired time-accurate and post-processed further such as to determine the complex transfer characteristics [2].

To address the sensor performance in a possible test environment, unsteady tests has been performed in a transonic test facility [3]. The facility features a rectangular test section of 100x110mm and is operated in continuous mode. Unsteadiness in the flow has been introduced using an elliptical rotating bar placed at a short distance downstream of the test section. The rotating bar induced variable blocking and by this led to periodic fluctuation of the flow in the test section. The thin-film electret sensor has been included in flush manner in the wall of the test section. For validation purposes a flush-mounted Kulite sensor has been included at the same axial distance. As the flow can be expected two-dimensional it is assumed that the unsteady pressure measured by the thin-film sensor and the Kulite are comparable.  A sketch of the test setup is shown in Fig. 3.

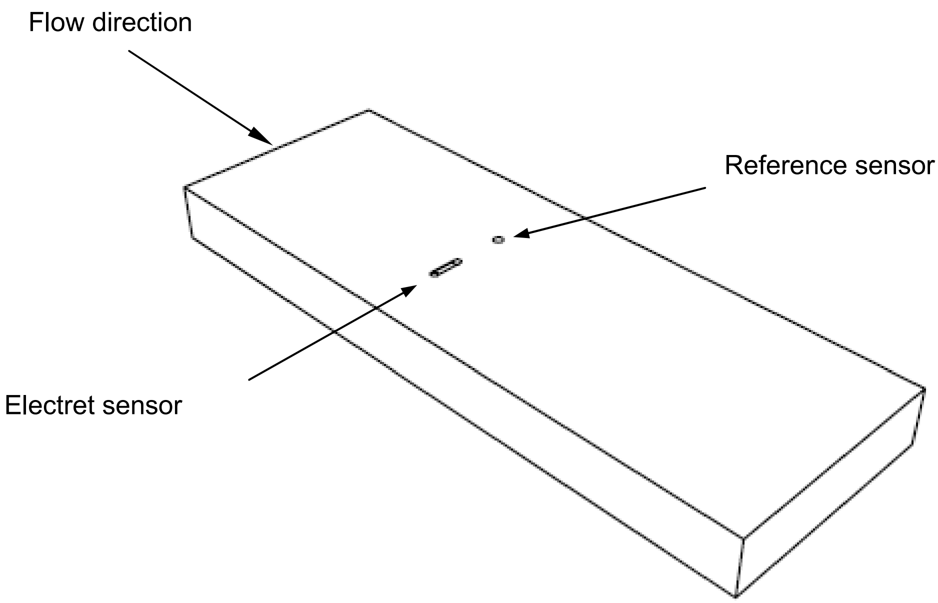



**Fig. 3: Sketch of sensor application test**

## RESULTS AND DISCUSSION

The characteristics of a typical thin-film electret sensor are shown below in Fig. 4. It comprises variations of magnitude ratio and phase versus frequency. For the present application the sensor has been characterized up to 2000Hz. The characteristics reveal predominantly capacitive behavior, although with a non-negligible resistive and inductive part. Here, two curves are shown that have been acquired from two different calibration runs. The curves show high repetitivity of the applied calibration procedure.

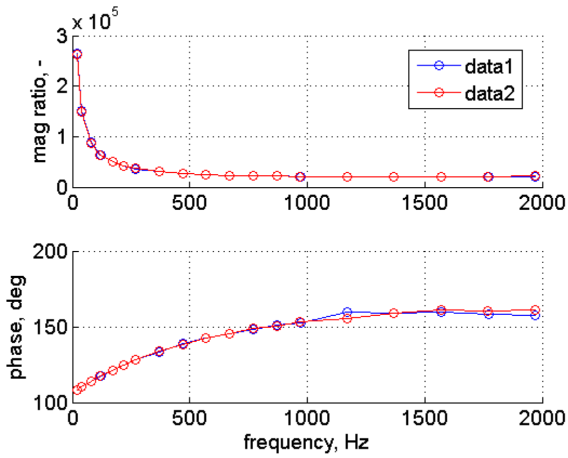
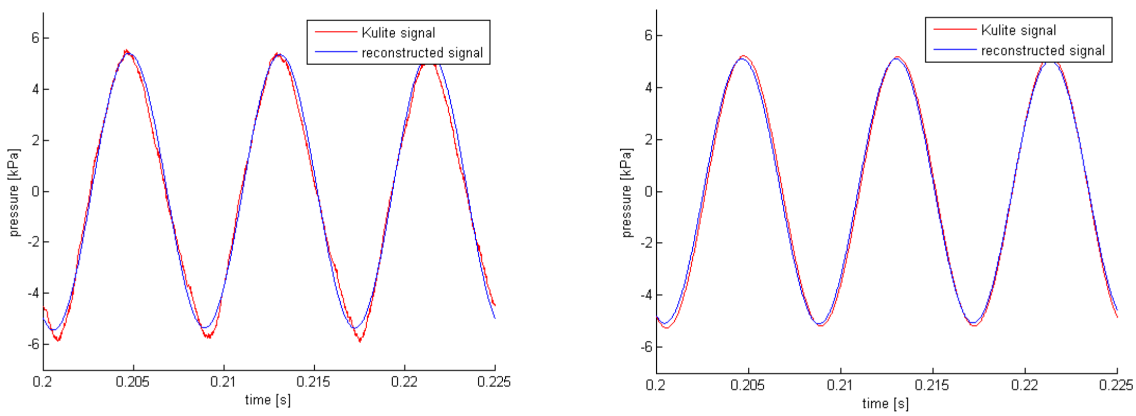



**Fig. 4: Transfer characteristics of thin-film electret sensor**

Applying the sensor characteristics the sensor signal has been used to reproduce the original pressure signal as described in [2]. This reconstructed signal is compared to the Kulite signal, which is assumed reflecting the true pressure signal as the sensor is flush-mounted. Comparisons of original signal (i.e. Kulite) and reconstructed signal are shown in Fig. 5. The reconstructed signal is compared once to the raw signal, once the base harmonic only. Whereas the first comparison gives an idea of the ability of the thin-film sensor to be used for measurement of an arbitrary signal, the latter addresses the accuracy of reproducing a certain harmonic content. In both comparisons the thin-film electret sensor performs well and allows for accurate acquisition of the measured pressure unsteadiness.




(a) (b)

**Fig. 5: Signal reconstruction from thin-film electret data; a) comparison to raw signal, b) comparison to harmonic content**

Results from first application tests are depicted in Fig. 6 using the aforementioned setup. The flow in the test section has thereby been perturbed at various frequencies between 15Hz and 145Hz. The data points reflect the measured pressure amplitudes at the excitation frequency. The thin-film sensor signal shows thereby fair agreement (difference <10%) at most frequencies apart from 75Hz. To date the cause of these differences is not fully understood. It has been observed that the electret sensor signal suffers from rather high signal noise content when being tested in the wind tunnel. The electret sensor signal is rather susceptible to signal noise it is as it is of the orders of few mV. Several techniques are currently under evaluation to cope with this problem, both on the sensor application as well as signal post-processing side. In the former area, various types of shielding are evaluated as well as the use of a "dead" sensor ("dead" in the meaning of shielded against pressure thus only picking-up eventual noise signal). On the post-processing side a wavelet transform method is being evaluated.

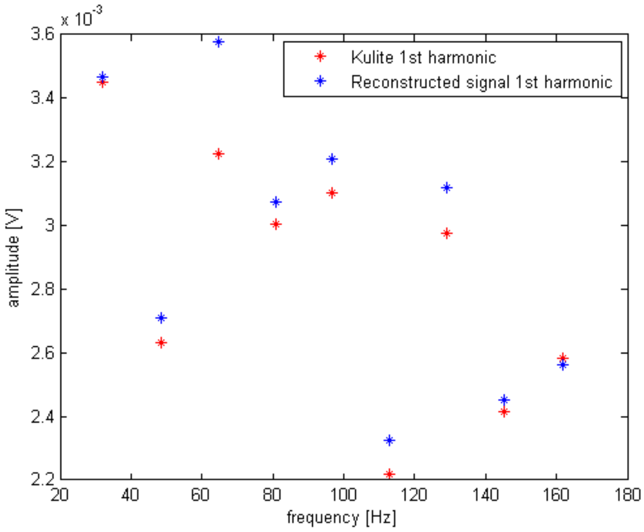



**Fig. 6: Comparison of data from thin-film electret sensor and Kulite sensor**

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