Use of Piezoelectric Films for NDT Applications

Silvère BARUT, EADS Corporate Research Center, Colomiers, France

Abstract. Poly(vinylidene fluoride) i.e. (PVDF) films and its copolymer with trifluoroethylene P(VDF-TrFE) have found many applications for electromechanical devices which perform energy conversion between the electric and mechanical forms. They have been used in several fields like alarms or stress gauges but have never been commonly used for Non Destructive Testing. EADS CRC has undertaken some evaluation tests using PVDF and copolymer for NDT applications. The results obtained are very promising for acoustic emission, ultrasonic inspection within assembled parts or in-service impact detection for instance. The advantages of those piezoelectric films compared to “traditional” piezoelectric transducers are numerous: flexible, light, easy to handle, designed at fashion, cost-effective... These properties should lead to new NDT applications which were unconceivable so far. This presentation will give an overview on recent tests and optimisations of PVDF transducers. The results will shed some light on the strong potential applications into the aeronautic field.

1. Introduction

Safety and weight saving have always been a priority in aircraft industry. The sensor technology has been improving while being miniaturised. Piezoelectric polymer films are quite a new type of sensors and they can be used in many fields. In aeronautics, this kind of sensors could monitor and insure aircraft structure safety when they are used in ultrasonic or acoustic emission transducers. The advantages of this kind of sensors is numerous like their mechanical flexibility, their size, their light weight, their wide bandwidth..., which means that they could be integrated into or on to an aircraft structure. That is why the Non Destructive Investigation and Structural Health Monitoring team (NDI & SHM) of EADS CRC has been deeply engaged for evaluation of the piezoelectric capabilities of such polymers used as ultrasonic or acoustic emission sensors for specific aeronautical applications.

2. General presentation of piezoelectric polymer films

KAWAI was the first to observe piezoelectricity properties of Poly(vinylidene fluoride i.e. (PVDF) in 1969. The first piezoelectric films were commercially available in 1975. PVDF is a semicrystalline polymer, which exhibits a variety of molecular conformations and crystal structures depending on the method of preparation. Extrusion of the PVDF polymer resin allows to obtained films who can be stretched in the machine direction and, or in the transverse direction. This process allows an orientation of the molecular conformation in the β phase which is the ferroelectric phase. PVDF films can be either uni-axially or bi-axially stretched. Copolymer films can be formed directly from a melt. They crystallize directly in the β phase and don’t have to be stretched.
Thin gold electrodes are sputtered on both surfaces of the polymer film. To obtain a piezoelectric film, it is necessary to apply a high poling electric field to the electrodes of the sample. Typical piezoelectric film samples realized are shown on figure 1.

Figure 1: Piezoelectric PVDF sheets

Such sheet can be cut into several pieces with as many designs as desired, which gives a wide range of possibilities according to the applications. Thicknesses of films range from a few microns up to two hundred microns. These physical definitions have a direct influence on the electrical properties (capacity value) of the film and also on its piezoelectric properties.

Capacity of the sensor: \( C = \epsilon \text{area/thickness} \)

Voltage delivered by the sensor: \( V = \frac{Q}{C} \)

With \( Q \), the quantity of the electric charge delivered by the sensor.

The application field of piezo polymer films is very wide. We can mention:
Force and pressure gauges - Microphones - Hydrophones - Ultrasonic transmitter-receiver - Impact localisation - Displacement detection - Medical imaging - Micro-actuators - Infra-red detection - Active vibration control...

3. Tests for aeronautical applications

The NDI & SHM team of EADS CRC has been interested in this piezoelectric polymer technology because of the capability of the sensors integration potentiality on/into structures. This kind of sensors could be used as acoustic emission or ultrasonic sensors when conventional piezoelectric transducers are not convenient because of the size, the weight, the thickness, the number or the price of the sensors. And another advantage is that the films are flexible, so they can be conformed even on curved structures.

3.1. Use of piezoelectric films into an assembly

Into an aircraft, the access to certain areas is sometimes awkward or impossible to proceed an ultrasonic inspection without disassembling the aircraft. Or for panels assembly for instance, the ultrasonic inspection is difficult because of multiple reflections, which may occur at the same time and induce a strong attenuation or disturbance of the received ultrasonic signal.
So, the idea would be to insert permanently sensors into designated areas and to proceed the ultrasonic inspection either remotely in pulse echo mode through a connected wire with no
need to handle a transducer (see figure 2), or through transmission using a standard transducer as emitter and the integrated films as receivers (see figure 3).

That is why EADS CRC has been evaluating the capacity of the piezo films to generate and receive ultrasonic waves, as well as the resistance of the films if they are integrated into an assembly which has been subject to a fatigue process. The figure 4 illustrates a configuration which has been tested.

The assembly was made of aluminium 2024T3 panels, 5 mm thick, using sealant between the panels. The PVDF films were bonded on the surface of the central panel on both sides. Several types of films were tested before and after a stress process (100 000 cycles, 42kN, 5Hz, 0.4mm displacement). Their dimensions were 12x70mm² by 28 and 52µm thick. The films were tested through transmission using a traditional probe (10MHz) on the surface to generate the ultrasound wave and the films as receivers, and they were tested in
pulse echo mode, so the films were used as emitters and receivers. Figures 5 and 6 present the corresponding a-scan signals from one of the PVDF film for each case.

![Figure 5: A-scan signal from the piezo film (through transmission mode)](image)

As we can see above, through transmission the signal to noise ratio is high and it has been confirmed all the way along the film. In presence of defect between the surface and the PVDF film the echo amplitude would be attenuated according to the size of the defect and the size of the emitter.

In pulse echo mode, multiple echoes are visible too although the signal is a bit perturbed. A smaller active area of PVDF would have been more appropriate and certainly more effective to detect a potential defect.

The piezo films responses were tested before and after the fatigue test, and most of them supported the fatigue stress as long as they had a protection like a Teflon coating.

These promising results proved that there is a real potential to use piezo films in such configurations. Many sensor designs could be realised and optimised according to the applications.

3.2. Use of piezoelectric films for Acoustic Emission applications

Acoustic emission (AE) is commonly used to monitor a sample during mechanical test in order to either improve the understanding of the sample mechanical behaviour or to localize a defect propagation and prevent a sample breaking.

The implementation of AE sensors in an aircraft in order to prevent a structure breaking or to detect damaging impacts during flight or in maintenance is one of the potential applications in Structural Health Monitoring in aeronautic.
The use of piezoelectric films could be very interesting for SHM because of their ease of integration (size, flexibility, light weight, low cost...). EADS CRC has undertaken some tests to evaluate piezoelectric films for AE applications mainly for impact detection. The first stage of the test was to stick standard piezo films (like 12*70mm² band) on to a composite work piece and evaluate the Hsu Nielsen source detection capability. The first hurdle was the electromagnetic disturbances, the noise level was very high and the Lamb waves sensitivity was poor. The second step of the work was then to optimise the sensor design for AE applications. Finally, the surface of the active part of the piezo film has been reduced to a few mm², the thickness increased to a few 100 of microns and above all they have been shielded. Figure 7 illustrates this kind of piezo film.

![Shielded piezo film](image)

Figure 7: Shielded piezo film

On figures 8 and 9 are presented the signals received from a piezo film at 50 and 250 mm from the Hsu Nielsen source on a thick composite work piece (15mm).

![Hsu Nielsen source detected at 50 mm](image)

Figure 8: Hsu Nielsen source detected at 50 mm

![Hsu Nielsen source detected at 250 mm](image)

Figure 9: Hsu Nielsen source detected at 250 mm
As we can see on the figures above, even if the piezo film is not as much sensitive as a standard AE sensor, the signal to noise ratio is very good (S/N=35dB at 250 mm from the source). The acquisition was done using standard AE equipment. This experiment proved that piezo films are sensitive enough to detect Hsu Nielsen source, which suggests that it will work for impact detection.

4. Conclusion

This article gives a brief overview on flexible piezo films potentiality for aeronautic applications such as ultrasonic testing and acoustic emission. There is a real benefit to use piezo films when standard sensors cannot cope with certain situations (access difficulties, weight, size, shape of the structure...). The sensitivity of such sensors is certainly lower than standard sensors’, however it would be sufficient for some designated and specific applications.

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