Continuous monitoring of composite materials

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Outline

- Introduction
- Sensors
- Optimisation of optic fibre sensor embedding
- Composite cure monitoring
- In-service health monitoring
- Discussion

Introduction

- In-situ monitoring of the cure process to improve the composite final quality.
- In-situ real time health monitoring procedure to guarantee the structure integrity.

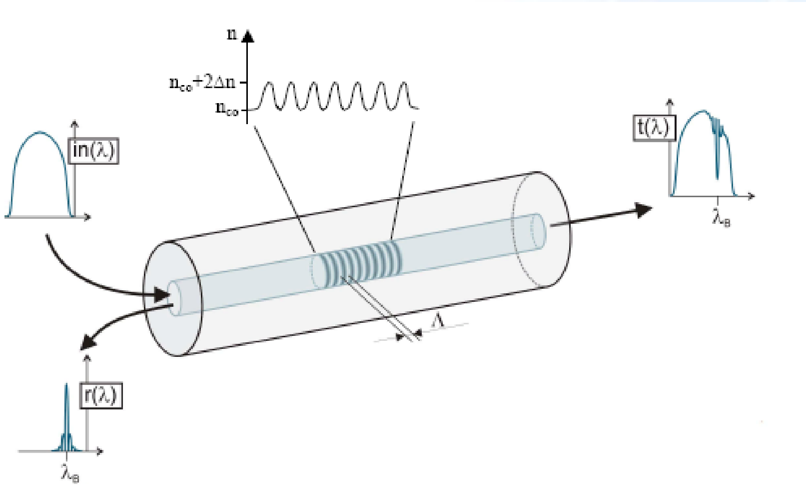
Sensors

- Optical fibre sensors
  - Fibre Bragg gratings
  - Extrinsic Fabry-Pérot interferometers
- Piezoelectric transducers

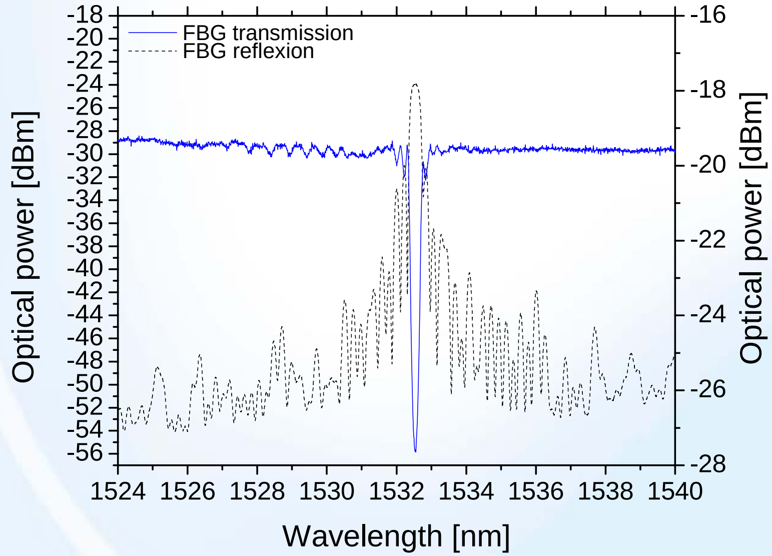
Optical fibre sensors

- Appropriate for embedding in composite materials.
- Translates the alterations observed in the characteristics of light.
- It is possible to associate those alterations to these variations.

- Fibre Bragg grating sensor



Fiber Bragg grating principle



FBG reflected and transmitted optical spectrum

A longitudinal strain variation, *Δε*, induces a variation, $\Delta\lambda_B$, of the wavelength of Bragg as follow

$$\Delta\lambda_B = \lambda_B\left(\frac{1}{\Lambda}\frac{\partial\Lambda}{\partial\varepsilon} + \frac{1}{n}\frac{\partial n}{\partial\varepsilon}\right)\Delta\varepsilon = \lambda_B(1 - p_e)\Delta\varepsilon$$

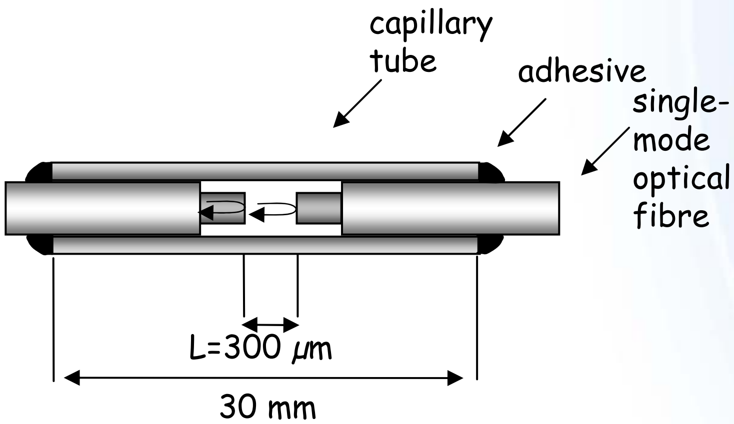
p_e : photoelastic coefficient

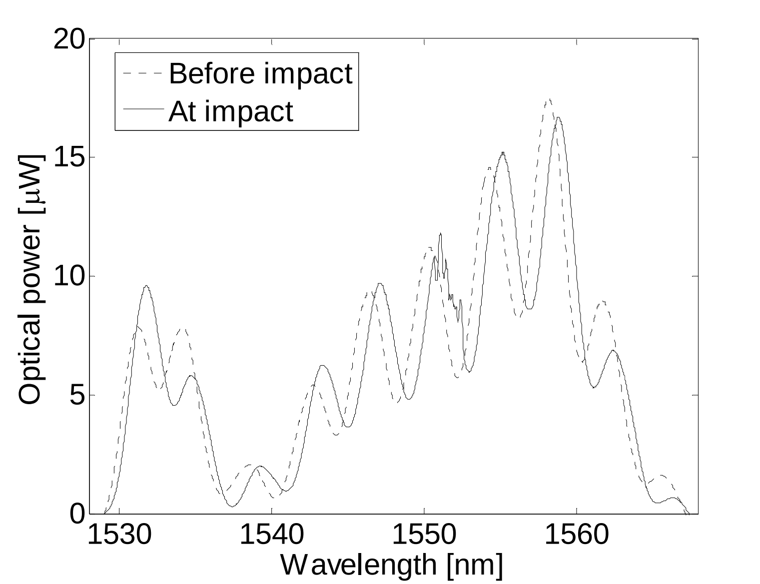
A temperature variation, *ΔT*, induces a variation, $\Delta\lambda_B$, of the wavelength of Bragg

$$\Delta\lambda_B = \lambda_B\left(\frac{1}{\Lambda}\frac{\partial\Lambda}{\partial T} + \frac{1}{n}\frac{\partial n}{\partial T}\right)\Delta T = \lambda_B(\alpha + \xi)\Delta T$$

α: fibre thermal-expansion coefficient,
ξ: fibre thermo-optic coefficient

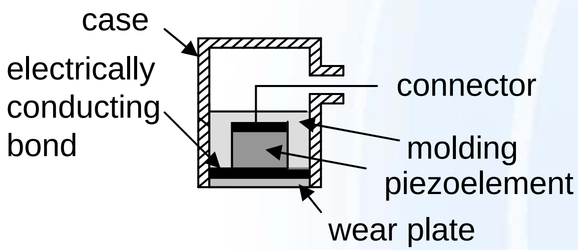
- Low finesse extrinsic Fabry-Pérot interferometer (EFPI)
- Based on the interference of two beams.





R. de Oliveira, O. Frazão, J.L. Santos, A.T. Marques, “Development of an optic fibre sensor system for acoustic emission sensing in FRP”, accepted for publication in Material Science Forum, 2005, www.scientific.net.

• Piezoelectric transducer



- Crystals which acquire a charge when compressed, twisted or distorted.

- Provides a convenient transducer effect between electrical and mechanical oscillations.

Optimisation of optic fibre sensor embedding

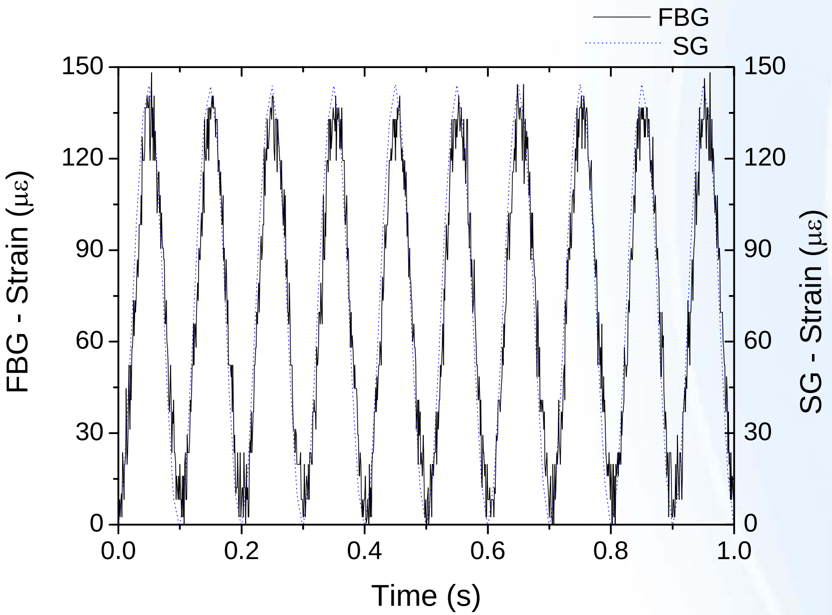
- A FBG sensor calibration is required.
- FEM modelling.

Composite cure monitoring

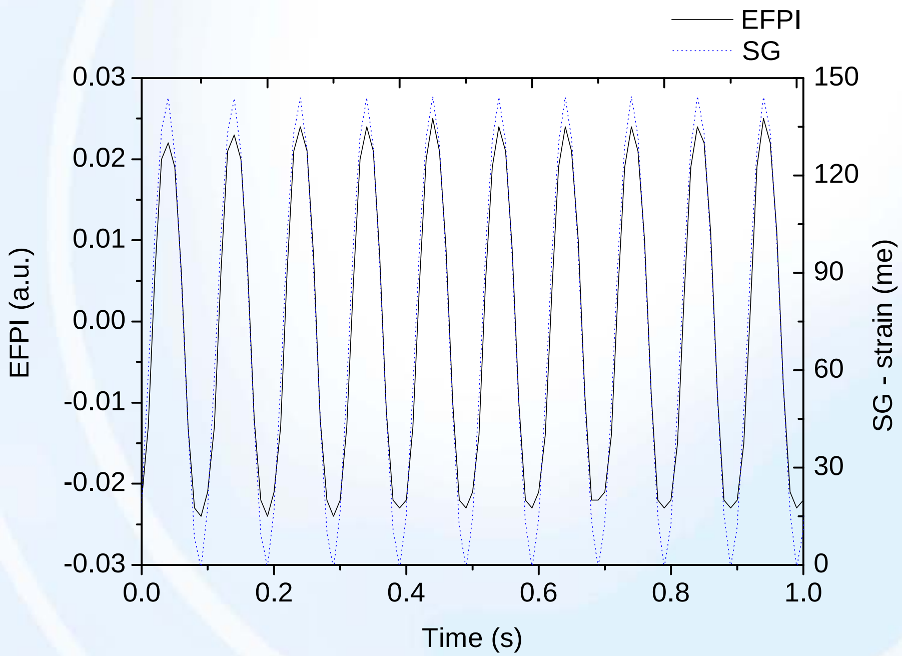
- Residual stress measurement using FBG sensor in composite materials made in autoclave .
- To obtain the optimal cure conditions
- Resin flow, temperature, pressure, internal stress measurement during RTM process.

In-service health monitoring

- From strain monitoring



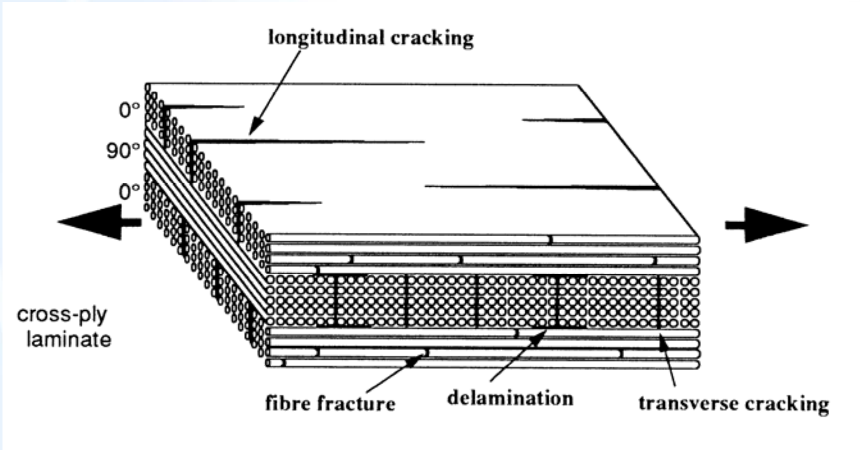
FBG sensor and electrical strain gages answers to dynamic solicitations



EFPI sensor and electrical strain gages answers to dynamic solicitations

A.C. Ramos, R. de Oliveira, A.T. Marques, "Health monitoring of composite structures by embedded FBG's and interferometric Fabry-Pérot sensors", II ECCOMAS Thematic Conference on Smart Structures and Materials", Lisbon, 18-21 July 2005.

- From AE monitoring
- Damage sequence of a cross-ply laminate
  - transverse matrix cracking in 90° plies,
  - fibre/matrix decohesion,
  - delamination,
  - longitudinal matrix cracking which develops along the fibre direction of 0° plies,
  - fibre fracture in 0° plies



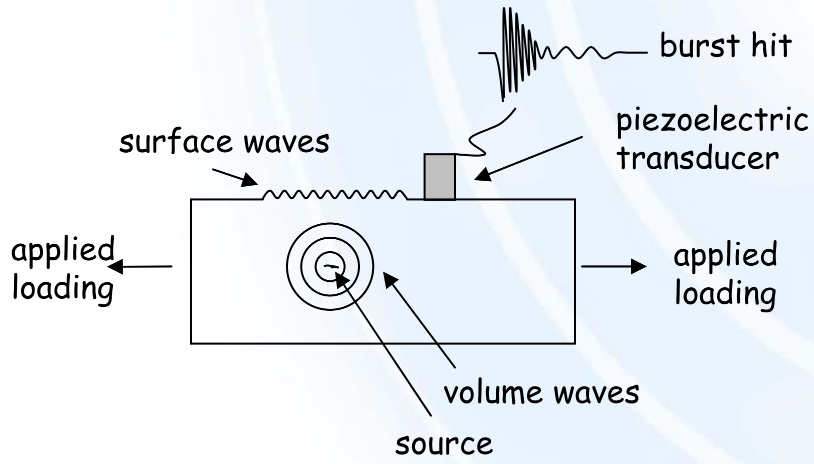
- An on-line health monitoring procedure capable to detect, acquire, and identify damage in fibre reinforced plastic composite materials is proposed to guarantee their safety

- The acoustic emission (AE) was chosen for its ability to detect evolutive defects during in-service life of structures

- The monitoring of the structure state requires the simultaneous processing of a lot of information.
- The artificial neuronal networks (ANN) have the capacity to process, in parallel, a great amount of operations.

Acoustic Emission

When loading a material, it starts to deform elastically. Elastic strain energy storage is associated with this deformation. Part of the elastic strain energy is rapidly released, at local stress redistribution such as that caused by growing cracks, in the form of elastic waves



Basic principle of AE method

- AE waves are related to the damage mechanisms. Depending on the type of damage, AE signals with specific characteristics may be expected.

- An unsupervised learning method seems to be more appropriate, in an attempt to discover specific characteristics in the AE signals.

- Chosen classifier: Self-organizing maps of Kohonen (SOM).

- The damage initiation could be determined from the AE activity

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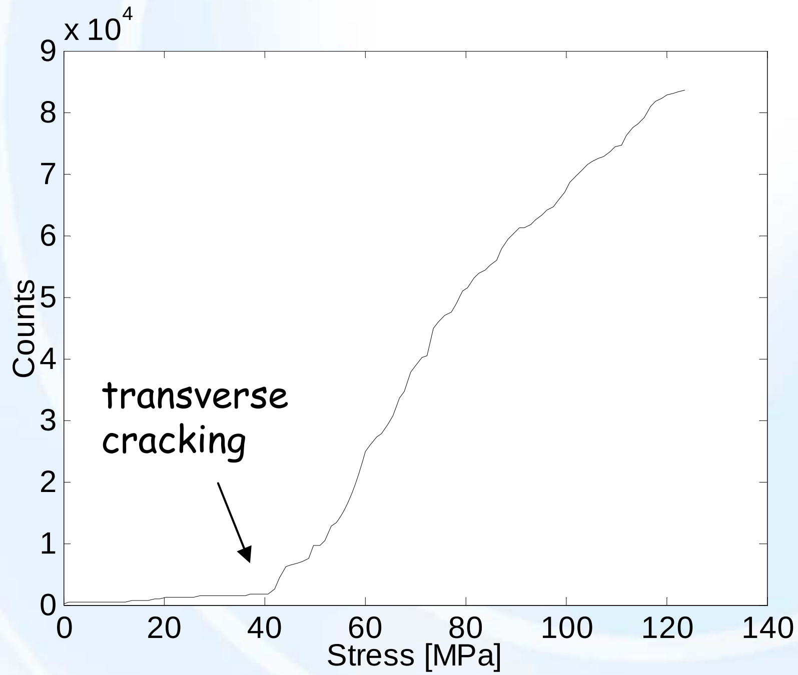
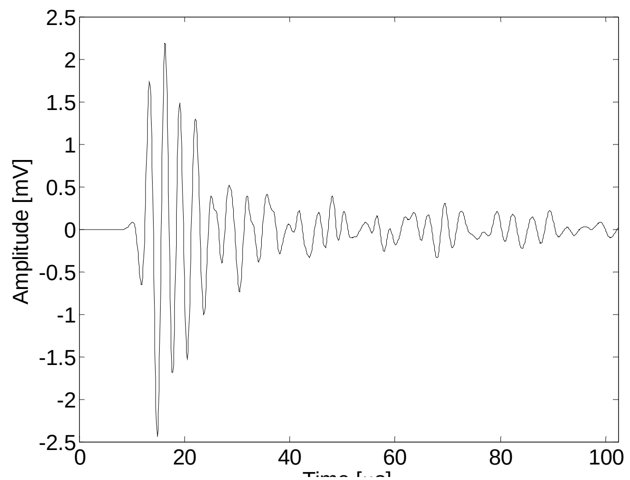
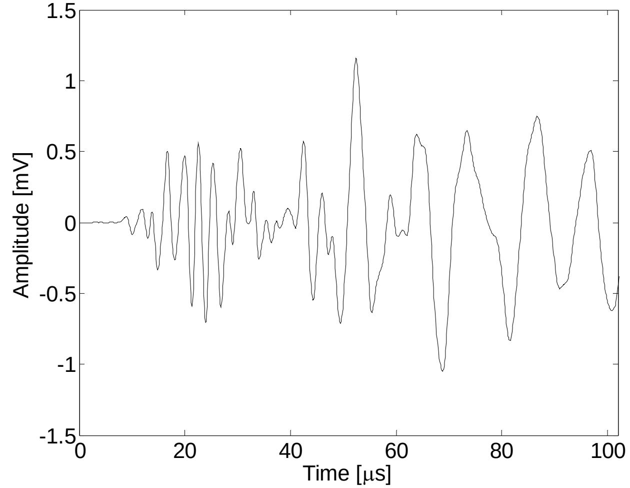


• Damage mechanisms were identified from the classified AE signals

transverse matrix cracking

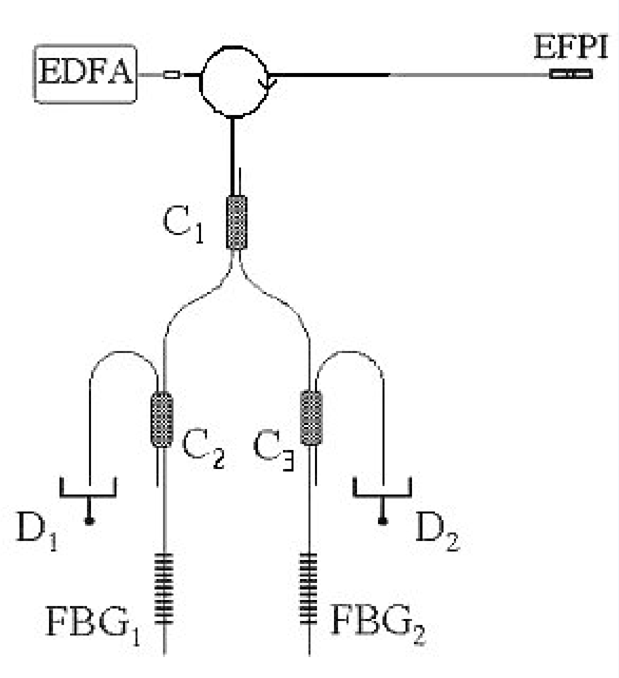


delamination

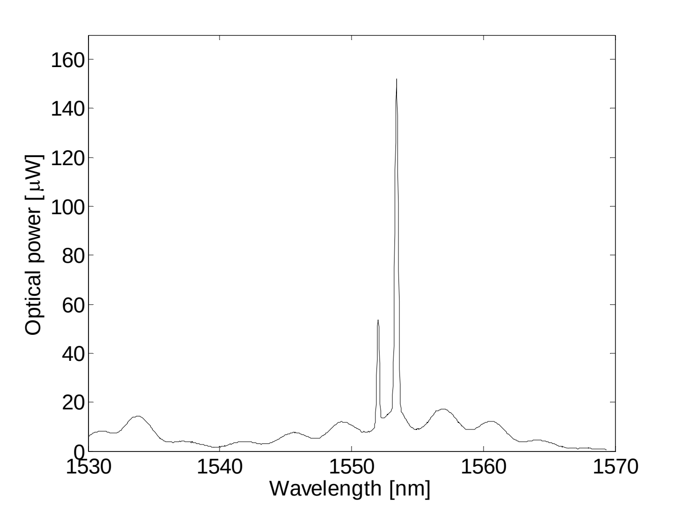


R. de Oliveira, A.C. Ramos, A.T. Marques, “Health monitoring of FRP using acoustic emission and artificial neural network”, II ECCOMAS Thematic Conference on Smart Structures and Materials”, Lisbon, 18-21 July 2005.

- AE detection using low finesse EFPI sensor



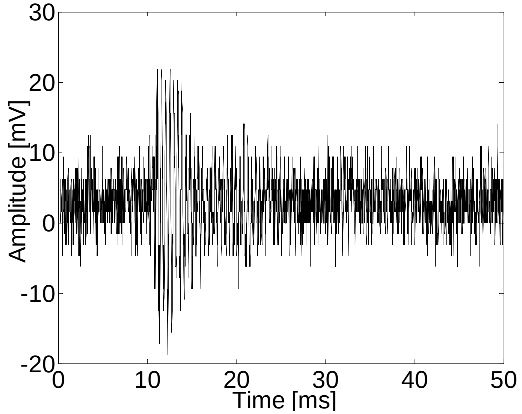
Experimental setup for generation of quadrature phase-shifted outputs



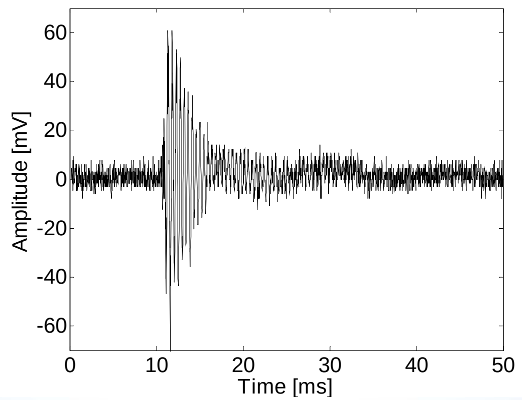
Optical power spectrum of the interferometric signal and the reflected light by the fibre Bragg gratings

R. de Oliveira, O. Frazão, J. Ferreira, J.L. Santos, A.T. Marques, "Optic fibre sensor for real time damage detection in smart composite", Computers & Structures, Vol. 82, Issue 17-19, 2004, pp. 1315-1321.

- Response to simulated AE waves

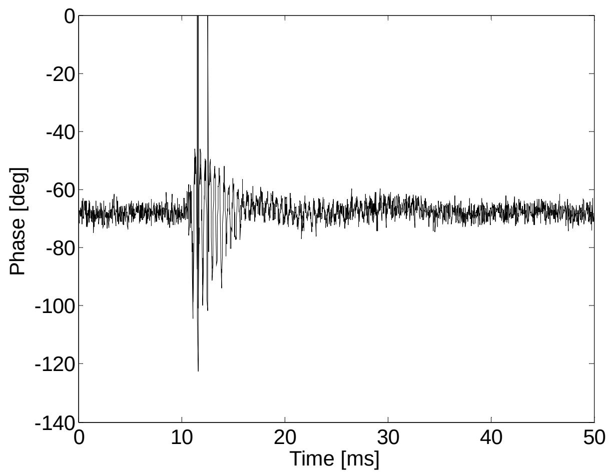


Photodetector 1



Photodetector 2

Phase variation due to the propagating wave



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- Discussion
  - Optic fibre sensors are appropriate for the conception of a nervous system for smart structures
  - The association of embedded sensors with processing techniques such as Neural networks permits to get real-time information about the composite structure.
  - A procedure was proposed to permit AE to be used for damage identification.
  - The fabrication monitoring will permit its optimization.

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