FEM model of Embedded Fibre Bragg Grating Sensor Response: Crack Growing Detection

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FEM model of Embedded Fibre Bragg Grating Sensor Response: Crack Growing Detection.

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1 Intro (Fibre reinforced plastic)

Fibre reinforced plastic (FRP) materials (composite materials) have been extensively used in aerospace, automotive, naval, civil engineering and wind energy applications. The main advantage of this material is the capability to be tailored for a specific application. This makes it possible to produce structures with enhanced properties and high level of customization, on characteristics such as lightweight, thermal expansion, chemical/corrosion resistance, fatigue behaviour, etc [1]. This increased use of fibre reinforced plastic materials requires a proper understanding of the failure mechanisms. Delamination is one of the most important failure mechanisms and is considered the most widespread mode of life reduction.

2 Crack/Delamination Detection by Embedded Fibre Bragg Gratings

Fibre Bragg Gratings (FBG) is a very a promising technology to track the presence of delamination/cracks in an operational FRP structure, due to its capability to be embedded in the material, without compromising the structural resistance. The FBG small size, 125 μm of diameter, makes it virtually non-intrusive to the material. FBG sensors, also have other interesting features, such high resolution, multiplexing capability, immunity to electromagnetic fields, chemical inertness and long term stability (fatigue behaviour).

A Fibre Bragg Grating is formed when a permanent periodic modulation of the refractive index is induced along a section of an optical fibre, by exposing the optical fibre to an interference pattern of intense ultra-violet light [2]. The photosensitivity of the silica exposed to the ultra-violet light is increased, so when the optical fibre is illuminated by a broadband light source, the grating diffractive properties are such that only a very narrow wavelength band is reflected back.

When any external phenomenon creates a change on the grating, like temperature, strain, compression, non-uniform strain fields, etc. this will create a change in the reflected light. However, different phenomena acting on the grating will make different changes to the sensor response (like a fingerprint), so it will be possible to track specific phenomena, which are characteristic of damage.

3 Finite Element Method Model

A novel method was developed to simulate the sensor output response of a Fibre Bragg Grating, when embedded in a host material (Composite material, polymer or adhesive) during a crack growing/damage event. This *sensor-damage-structure* model provided a tool to study the application of this monitoring technique in other locations, by predicting the sensor output and deciding, based on this, the most optimized sensor-structure configuration.

In this study case, was addressed the delamination in the trailing edge of a wind turbine blade, as an example. The trailing edge is modeled as a Double Cantilever Beam (DCB) under different fracture modes, and the sensor simulated by an array of embedded FBG sensors. This sub-model (DCB-trailing edge) can be extrapolated to a model of a full structure (Full Wind Turbine Blade), and simulates the response of sensors under different types of failure, as showed in figure 1.

A 2D and 3D Finite Element (FEM) DCB model was developed, where different loading contions (ranging pure Mode I to pure Mode II fracture modes), simulate the differente fracture cases that can happen in this structure. The crack growth in the DCB specimens was modeled using cohesive elements, which describe the cohesive law that governs the crack growth mechanism. The model material/geometry properties were based on a real trailing edge configuration used by the *DTU 10MW Reference Wind Turbine* [3].

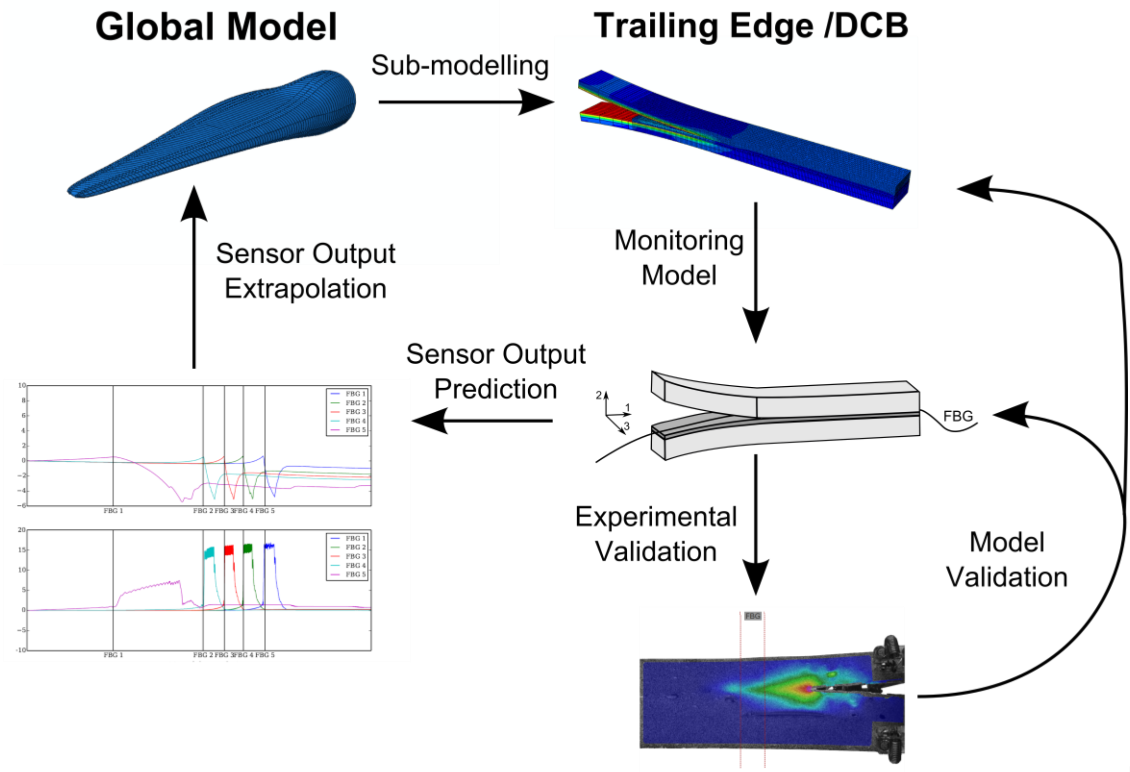

Figure 1: Model scheme of crack/delamination detection by embedded fibre Bragg gratings.

4 Experimental Validation

DCB specimens with the same material-sensor configuration as the model, were tested in a loading device commonly used to determine material fracture properties (developed by Sørensen [4]). The DCB specimens were instrumented with an array of FBG sensors embedded in the host material, and a digital image correlation technique was used to determine the presence of specific phenomena caused by the crack growth to correlates FBG sensor response with the model prediction.

A good agreement between the finite element model and the experiments was found. The FEM was able to represent the crack growth under different loading cases, and the sensor output model matched the experiments, showing the expected sensor response ("fingerprint") when fractured by a crack.

5 Conclusion and Achievements

It is possible to extract information from the sensor that is independent of the loading type, geometry and boundary conditions, which depend only on the proximity of a crack. This fact, allows the application of this monitoring system in general composite material structures. The prediction of the sensor response by the FEM model makes it possible to study the application of this monitoring technique in other locations, predict the sensor output, and decide on the optimized sensor-structure configuration.

This "*Structure-FBG Finite Element Model"* concept can have an impact in condition monitoring methodology and maintenance, by optimising the measurement by sensors, enabling more diverse and accurate damage detection, giving better characterization of the damage (type and size), and giving information for prediction of the residual structural life, and if possible, repair.

6 References

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