Damage Detection of Wind Turbine Blade using Hybrid Dense Sensor Networks

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1 Justification

Damage detection of wind turbine blades is difficult due to their complex geometry and large size, for which large deployment of sensing systems is typically not economical. The solution proposed in this paper is to develop and deploy dedicated sensor networks fabricated from inexpensive materials and electronics. The authors have recently developed a novel skin-type strain gauge for measuring strain over very large surfaces. The skin, a type of large-area electronics, is constituted from a network of soft elastomeric capacitors. The sensing system is analogous to a biological skin, where local strain can be monitored over a global area. In this paper, we propose the utilization of a dense network of soft elastomeric capacitors to detect, localize, and quantify damage on wind turbine blades. We also leverage mature off-the-shelf technologies, in particular resistive strain gauges, to augment such dense sensor network with high accuracy data at key locations, therefore constituting a hybrid dense sensor network. The proposed hybrid dense sensor network is installed inside a wind turbine blade 1:25 scale model, and tested in a wind tunnel to simulate an operational environment. Results demonstrate the ability of the hybrid dense sensor network to detect, localize, and quantify damage.

2 Introduction

In this paper, the problem of damage detection on a wind turbine (WT) blade (Ciang, 2008) using novel large area electronic (LAE) strain sensors combined with mature off-the-shelf resistive strain gauges (RSGs) in a hybrid dense sensors network (HDSN) is investigated.

The novel LAE consists of a distributed network of soft elastomeric capacitors (SECs) engineered to measure local strain over mesosurfaces (Laflamme, 2013). These SECs are fabricated from an inexpensive mix and can easily cover large areas, at low costs. Each SEC (black squares figure 1(b)) transduces local strain into changes in capacitance, providing a direct signal-to-strain map. Algorithms need to be developed and tested in order to provide condition assessment capabilities using strain data.

The proposed HDSN is deployed inside of a 1:25 scale model WT blade, tested in a wind tunnel to simulate an operational environment. The ability of the HDSN to detect, quantify, and localize damage to further the understanding of the structural behavior of mesosystems, defined as full scale structural components, will be addressed.

3 Methodology

The HDSN, consisting of 12 SECs and 8 RSGs, is deployed onto the inside surface of a panel (WT blade shell) of the 1.3 meter model WT blade. The HDSN layout is illustrated in figure 1(a). Figure 1(b) is a picture of the fiberglass panel that was attached to the blade model with 12 SECs and 4 of the 8 RSGs mounted. Additionally, the remaining 4 RSGs where added after the panel was attached to the model. The model was mounted vertically in a closed-loop wind tunnel with the root restrained in all

6 degrees of freedom. Vibrations where induced via buffeting through an artificially generated turbulent airflow. Various damage cases were induced into the fiberglass substrate by cutting along the dashed line in figure 1(a), from the centre outward. Data was collected for the undamaged condition, as well as from crack lengths varying from 2 cm to 13 cm, in 1 cm steps. The induced cut is 2mm wide.

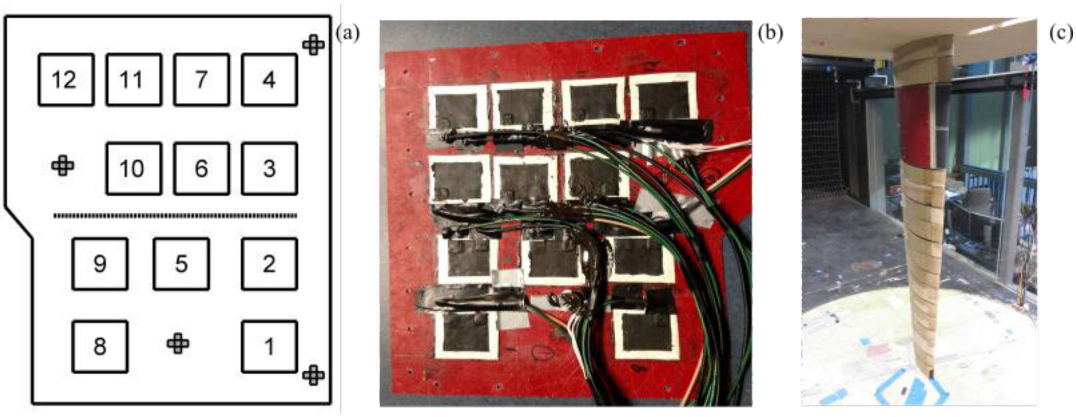

Figure 1. Experimental HDSN configuration; (a) schematic, where squares represent SECs and crosses represent two RSGs measuring strain in orthogonal directions; (b) picture (mirrored) of the sensor configuration (RSGs under wires); (c) blade model in wind tunnel.

4 Validation

The ability of the HDSN to function as a sensing skin, capable of detecting, localizing, and quantifying damage is validated. The algorithm consisted of taking the Fourier transform for each sensor signal, and extracting the magnitude of the first spectral peak, that is a local measure of the modal strain energy. Figure 2 is a plot of the peak magnitude as a function of crack length for selected sensors that are parallel to the induced damage. The capability of the HDSN to track the changing load path can be observed through the relative response of the SECs. The simulated crack damage induced from the centre out causes the load path to shift from the centre to the exterior of the substrate, which explains the shift in spectral energy from sensor 5 to sensors 2 and 9. Once the crack extends passed sensor 9 (9 cm), the magnitude of the first spectral peak measured at sensor's location reduces.

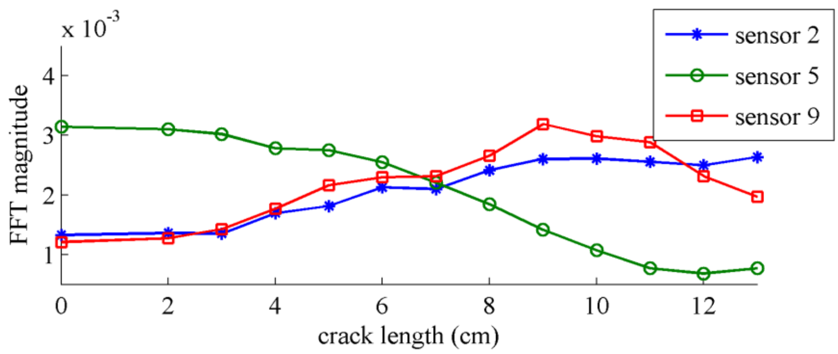

Figure 2. fourier transform response of selected sensors

5 References

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