Demonstrating optical fiber-based sensing technology for impact detection and localization

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Abstract

Ensuring the structural integrity of critical composite aerostructures is of major concern in the area of aerospace design, airworthiness certification, and aircraft operation. Impact damage is one of the major threats to the structural integrity expose to vibration loading combined with elevated temperature. This is especially important for composites material-based structures due to their lack of plasticity energy absorbing mechanism.

In principle, fiber optic sensors, and in particular fiber Bragg gratings (FBG) are excellent candidates to replace piezoelectric sensors due to their high directional sensitivity to mechanical strain, small size, immunity to electrical interference and capability of dense multiplexing. Moreover, for composite structures, such optic fibers sensors can be easily embedded into the structure, eliminating the need for sensor protection, and can be used to monitor also strain and temperature during service.

In this work, we demonstrate a concept and system for the detection and localization of high velocity foreign object impacts in a composite part, using high-speed and wide frequency-band fiber Bragg grating (FBG) interrogation. We describe an experimental validation of the concept, whereby 4 FBG sensors, inscribed along a single optical fiber, were mounted on a 3-meter section of a rotor blade, and several types of projectiles - steel, silicon carbide, and stones - were launched into the blade at speeds between 100 m/s to 200 m/s. The FBG sensors were interrogated with an innovative high-speed interrogator, at a sampling rate of 10 Msps for each sensor, simultaneously.

The ability of the high-speed interrogator to record elastic waves that are emitted from the impact location and propagate along the composite skin of the blade to a distance of several meters is demonstrated. Further, we discuss the importance of high-speed sampling both for accurate estimation of impact energy, and consecutively, its severity, and for precise determination of the impact location. This paper describes the core principles of PerCiv's high-speed FBG interrogation technology and outlines further provisions for equipment miniaturization, as well as challenges related to the frequency response and the sensitivity limitations of FBG sensors.