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CARBON COMPOSITE STRUCTURES WITH EMBEDDED FIBER OPTIC SENSORS: A SMART PROPELLANT TANK FOR FUTURE SPACECRAFT AND LAUNCHERS

Abstract

Modern spacecraft systems and launch vehicle design is more oriented towards reducing system-level design and assembly complexities. In order to maintain high overall system performance while reducing these complexities, the use of smart materials and smart structural components is becoming of more interest to space systems' designers. The paper will present a concept of smart space structures, in particular carbon fiber composites embedded with Optical Fiber Sensors (OFS) for spacecraft and launch vehicle applications. Although the application is of interest as well to electric and hybrid propulsion with suitability for a variety of relevant propellants, the case study presented is on smart propellant tanks to be used in launch vehicle's upper-stage chemical propulsion, utilizing gaseous and liquid fluids with specific interest in green propellants (i.e., EIL and NOx classes). This study will discuss the typical mission and operational requirements for such tanks and the smart features enabled by the optical fiber sensors. For the latter aspect, a quantitative comparison between Fiber Bragg Grating sensors (FBGs) and Distributed Optical Fiber Sensors (DOFS) based on Optical Frequency Domain Reflectometry (OFDR) is presented to highlight their core performance parameters, such as the sensing range and spatial resolution. The proposed smart tanks utilizing optical fiber sensors are found to be capable of providing precise readings of static and dynamic strain as well as temperatures on a wide range. The increased performance and reliability come with a reduction in size, mass, and power consumption compared to the conventional electronic sensors. Optical fiber sensors embedded in carbon fiber structures have proved capability in providing accurate real-time measurements of temperature and monitoring structural integrity while detecting precisely possible points of rupture and failure. The applications of fiber optic sensing in smart propellant tanks may extend to detecting fluid leakage and providing increased precision in propellant gauging and can be used in on-ground qualification, pre-flight testing, as well as in-orbit operation and health monitoring.