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Raja V. L. N. Sridhar
Santosh Kumar *Editors*

Advanced Optical Sensors for Aerospace Applications

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Contents

FBG Sensor Applications in Aerospace Engineering

V. R. Balaji, M. A. Ibrar Jahan, Gaurav Kumar Bharti, Archana Yadav, Srujana, and Rajini V. Honnungar

Abstract Fiber Bragg grating (FBG) sensors have emerged as a preferred choice in various industries, including telecommunications, civil, aerospace, and automotive, for monitoring various parameters due to the advancements in fiber optic technology. They possess exceptional qualities, including outstanding sensitivity, flexibility, lightweight, multiplexing, and immunity to electromagnetic interference. FBG sensors are an exemplary choice for aerospace engineering applications that require remote detection, high precision, and lightweight design. These sensors leverage changes in fiber properties caused by perturbations like polarization, strain or temperature etc. When these perturbations occur, they either alter grating pitch or modal index, resulting in a relative resonance wavelength shift. Measuring this shift enables the detection and quantification of physical changes, yielding essential data for structural integrity evaluations. This chapter covers the utilization of FBG sensors for monitoring the structural health in aircrafts/ Avionics industry. It also covers the case studies that emphasize using FBG for Structural Health Monitoring (SHM) in aircraft, showcasing their efficacy in practical situations. It also illustrates how SHM can contribute to safer, more efficient operations in aerospace engineering.

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1 Introduction

Extensive, intricate, and expensive engineering buildings are primarily designed for longevity. This is particularly recognised for civil engineering structures as well as Ships, Heavy equipment/Machinery, Aeroplanes and Trains. Several among these components are utilised for degradation. An engineering structure is inherently intended to endure degradation for a certain foreseeable lifespan. As the lifetime extends, it turns out to be very challenging to forecast. Such a structure may consequently needs a plan for maintenance/reparability. Historically, this has frequently been insufficiently addressed and may still be the case now. The rationale is that most limited-life goods are seen as having a longer lifespan after their design is finalised. An excellent instance is aviation vehicles. Aircraft, historically constructed entirely from metals, are engineered for a predetermined number of flying hours, determined by typical usage in relation to fatigue. Individuals familiar with fatigue testing understand that the fatigue life of a certain material exhibits considerable variability. A score of two in life is typically considered low. Given that aeroplane structures, and maybe others, are engineered for a low chance of fracture, it is improbable that a component would shatter after meeting its design specifications, unless it was intentionally constructed to be fail-safe Owing to dispersion, it may persist for up until it has already or maybe longer [1]. The inquiry thus emerges: depending on what conditions can we sustain the use of this building beyond its original intended lifespan?

Flight hours, typically employed as a metric for aircraft utilisation and longevity, may not be the only criteria. An aeroplane is frequently used outside the circumstances under which it was originally constructed. This is evident in the military aviation sector. Can the aircraft be utilised until the designated flying hour objective has been met? Initially, the response is: No! One reason is that environmental loads contribute to corrosion, which is challenging to forecast and measure, necessitating determination by inspection. Exceeding the design objective in the context of an operating life update necessitates a significantly revised corrosion in section strategy. A further rationale for not immediately prolonging the operational lifespan of an undamaged structure is that the operating circumstances may differ from those present at the time of the structure's original design. An aircraft, particularly in the military industry, may be required to transport various payloads (e.g., diverse weaponry) and operate within varied flight envelopes owing to advanced flight control systems. Can the existing framework endure this? A reconsideration of the structure is necessary to address this question. Regardless of the supplementary work needed to prolong the operational lifespan of a fading infrastructure, it is prudent to do this form of study, particularly when an infrastructure is expensive. This is particularly accurate for aeroplanes, as the incidents of September 11 have not significantly altered the circumstances. Aircraft have become integral to public transit and defence. Innumerable aircrafts, numbering in tens of thousands have been manufactured throughout the years, with a large number of them continuing to be in operation. Experiences incurred with these flying machines, have revealed that there has been an escalating demand for inspection and maintenance, increasing year after year. It was analyzed that an EF-111A, a fighter plane, required roughly 2200 manhours for inspection and maintenance alone, just for a single aircraft; a full fleet would require many times that number. In 1996, the observed figure rose substantially to requiring manhours exceeding 8000 annually per Aeroplane. Often, magnitude of such undertaking is significantly influenced by the aircraft's usage, complexity, and dimensions. Kudva said that some members of 1993 were inspected solely, with costs of 88, 4, and 29 USD for every hour flown by an F-18 and a T-38, respectively [2]. Table 1 depicts the military ageing aircraft overview.

Any design that is damage-tolerant permits the development of a damage. This can be accomplished by either allowing a fissure to develop to a specific length, at which point, the fissure halted either with the use of a crack-stopper or when the very component fractures, which would transfer the forces acting on it to another part. However, damage tolerance can also be established by presuming that a fracture is present at a location that is difficult to inspect and determining the extent to which the deformity is permitted to expand before it becomes critical.

In all the instances, a fatigue timeline calculation must be conducted, regardless of whether the design is damage-tolerant or safe. This necessitates a load spectrum, 'Kt' which is a factor taking into consideration the stress concentration, a curve (S–N curve) mapping the fatigue timeline, and the stress concentration in the grooves need to be described. The Fatigue timeline curve is experimentally determined through the notched modules using corresponding value of the stress concentration factor (Kt) or through data recording the fatigue, retrieved from unnotched specimens with use of the relationship between notch and strain [3]. The Palmgren–Miner damage accumulation rule is now employed to calculate fatigue life damage for each cycle as expressed in Eq. (1)

Table 1 Overview of ageing military aircraft

Aircraft type	Built year	Total service	Life extension
Boeing B-52H Stratofortress	Mid 50	94	2045
Boeing 707/C-137/C-18/KE-3	Mid 60	97	2030
Boeing F/A-18 Hornet/Super Hornet	1978	1762	2019
BAE Hawk/Boeing T-45 Goshawk	1976	641	–
Northrop T-38	1959	685	2040
Panavia Tornado	1974	746	2018
MiG-21 (incl. licences)	Mid 50	3324	–
L-39/L-39 Albatros/L-159	Mid 70	2233	–
BAE Hawk/Boeing T-45 Goshawk	1976	641	–