Distributed Fiber Optic Sensor Based Structural Health Monitoring of Composite Structures: Issues & Challenges

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Composite materials have been in use for aerospace applications for more than three decades. Composites offer the designer the flexibility of combining multiple smaller components into a single large component using co-curing technology. Although composites have a higher ability than metals to withstand fatigue loading, they have a lower resistance to impact. Moreover, unlike in metals where impact results in a visible dent or damage, impact on composite structures results in internal defects, which cannot be detected through a regular visual inspection. Scheduled inspections lead to considerable increase in maintenance cost & down-time of the aircraft. Additionally, these methods sometimes are limited by the inaccessibility of interior parts which may leave damages unidentified. Any solution, which continuously monitors the status of the structure and informs the concerned personnel, can lead to a timely and cost effective solution to this problem. In this regard, various aircraft industries and research labs are pursuing development of systems and methods for structural health monitoring of composite aircraft structures. The lifecycle cost of aerospace structures can be reduced significantly if continuous and autonomous condition based structural health monitoring (SHM) systems can be integrated into their design.

Structural Health Monitoring (SHM) has been defined in the literature as the "acquisition, validation and analysis of technical data to facilitate life-cycle management decisions". The use of SHM systems has the potential to provide greater confidence to the user on the integrity of the structure. Having structures equipped with an SHM system will enable the structure to inform the 'maintenance' about its overall health based on the information gathered from the built-in sensors & processed by SHM algorithms.

The advent of fiber optic sensing technology has opened the possibility of incorporating *"fiber optic nervous system"* in the composite structure akin to human skin. Fiber optic sensors have several advantages such as low weight, high sensitivity, immunity to electromagnetic interference, multiplexing capability, etc. Fiber Bragg Grating (FBG) sensors and Scattering based distributed sensor are the most promising technology which are being pursued wordwide. FBG sensors provides a quasi-distributed sensing option along the length of the fiber at user defined specific locations on the fiber. Scattering based sensing technology relies on the naturally occurring random imperfections in the fiber optic cable to attain readings. Both scattering and FBGs use various demodulation techniques for sensor interrogation. Wavelength division multiplexing (WDM) is the most preferred demodulation technique for FBG based technology due to high signal to noise ratio at specific spatial locations on the fiber thereby limiting the number of sensors in a fiber. OFDR is well suited for applications that require monitoring more than just critical points. This may prove extremely useful to achieve full field strain profile measurement along the fiber length.

As the damages in the composites, at a nascent stage, do not change the global structural behavior, hence it is extremely important to pick up the local changes in the strain pattern in close proximity to the damage site. OFDR based sensor demodulation technique suitably provides the option of measuring the small changes in strain due to onset of damage by having multiple sensing points along the length with high spatial resolution (of the order of few mm).

The enabling components to realize an SHM system are (i) Structural design & analyses to identify the sensor locations (ii) Sensor integration & interrogation and (iii) SHM methodologies & algorithms to process the sensors data to determine loads & the extent/severity of damage, if any, (diagnosis) and remaining useful life (prognosis). The above mentioned components of a SHM system and their respective maturity level, especially from implementing sensing technology & measurement point-of-view, on an aircraft structure, classifies the SHM system into three broad categories namely (i) On-line SHM, (ii) Off-line SHM and (iii) Hybrid SHM system.

The group at Advanced Composites Division (ACD) in National Aerospace Laboratories (CSIR-NAL) has been pursuing the development of an aircraft SHM system using fiber optic sensors. The talk will cover the various aspects of distributed sensing technology and their approach of implementation on an aircraft structure. The experience gathered over more than a decade of using the fiber optic sensors for SHM application covering the various issues and challenges in terms of sensor characterization, rugged installation and embedment on the composite structures, sensor measurement system and algorithms for damage and load estimation through various test box studies using both FBG and distributed sensing technology would be discussed. FBG technology has also been demonstrated at flight test level wherein the sensor measurement was carried out in real time and data processing for damage and load estimation has been done post flight test. In the hybrid SHM system approach, division has developed the technology using bare fiber optic sensors. In this case the sensors would be the integral part of the structure. However, the measurement would be done between the flights to assess the structural integrity. It is suggested that a judicious combination of both FBG and distributed sensing technology would pave the way for implementing the SHM technology for aircraft structures.

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Bio Data

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Nitesh Gupta completed his B.Sc. in Electronics from Nagpur University in 1997. Subsequently he completed his M.Sc. (Honors, Electronics) and M.Tech. (Instrumentation) from Devi Ahilya Vishwavidyalaya (DAVV), Indore in 1999 and 2000 respectively.

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His current research interests include: Fiber Optic Sensing Technologies, Image Processing, Structural Health Monitoring. He is a life member of Institute of Smart Structures & Systems (ISSS) and Indian Society for Advancement of Materials and Processing Engineering (ISAMPE). His research efforts have led to 1 Patent, 1 Copyright, over 5 international journal articles, more than 35 conference papers & over 25 internal technical documents.

He is recipient of various individual & team awards namely NAL's Excellence in Research Award (2006), ISAMPE Award for Smart Technology Development (2009, 2011), CSIR-NAL's Young Scientist Award (2012), National Instruments Engineering Impact Award in Systems Category (2016), JEC Asia Innovation Award in Thermoset Category (2016), Technology Innovation in Petrochemicals and Downstream Plastic Processing Industry (2016).