Abstract

Structural testing deals with sensing of health parameters such as strain, temperature, vibration, etc. of different structures like aircrafts, ships, bridges, dams, buildings, etc. and it is important from the viewpoint of predictive and preventive maintenance of these structures. Fiber Optic Sensors (FOS) have become popular in the recent times for structural test applications due to many advantages, which include quasi distributed sensing, electromagnetic insusceptibility, environmental ruggedness, high frequency sensitivity, etc. This thesis work deals with development of test procedures and instrumentation for structural and flight testing of aircraft components and full aircraft, using fiber optic sensors. The results obtained have been validated using conventional Resistance Strain Gauge (RSG) sensors.

The first part of the thesis concentrates on simple technological aspects of Carbon Fiber Composites (CFC). The classification of composites, characteristics of laminated CFC composites and an overview of damages in composites, including types of damage/defects in composites & their classification are presented. Further, the basic concepts of Fiber Bragg Gratings (FBG) sensors and their applications are described. Also, the different ways of test article mounting in a test rig in the absence of parent structural member and their effect on test results, are brought out. The results of CFC coupon-level tests undertaken, and the results obtained which gave confidence in the usage of FBG sensors for strain measurements on aircraft components and full aircraft, are discussed.

The second part of thesis deals with the experimental work undertaken on strain measurement on aircraft parts such as CFC air brake panel, wing test box, half wing on flexible test rig, full aircraft, etc... The test-rig design methodologies, instrumentation development, investigations of structural behavior under load, etc. are undertaken and results obtained along with analysis & comparison with standard sensors, are presented. In addition, the control-rod load measurements on a flying aircraft using Extrinsic Fabry-Perot (EFPI) sensors are presented.

A brief overview of the research and developmental work undertaken is given below: Testing of wing test box with pylon attachment points in a rigid test rig assembly is undertaken. Loads and reactions are maintained as in flying condition using a multichannel servo hydraulics actuator. The RSG and displacement data are validated with Finite Element Method (FEM) results. These data can be used for validating the structural design of the composite wing box for the flight load conditions.

The independent wing test with major wing root fitting attachment points in a flexible test rig is carried out with an extensive RSG sensor network. The fuselage attachment points are maintained with controlled reactions through loading actuators. With the flexible rig design concepts, the wing does not feel the absence of the parent fuselage structure throughout the

test. The main fitting reactions, displacement and selected RSG sensor outputs are compared with the FEM data. The problems encountered in the deployment of many RSGs in routing of cables in this test, motivated the deployment of fiber optic sensors for the subsequent applications.

The health monitoring of a CFC air-brake panel, instrumented with Fiber Bragg Grating sensors, is described. Based on FEM analysis, the critical locations have been identified for monitoring the strain. The Bragg resonance wavelengths for different sensors have been chosen based on the magnitude and nature of strains expected at different locations. The optimal layout for routing four FBG strings of eight sensors each is formed, and the sensors are fabricated accordingly. The sensors are bonded as per the layout design and the strain data collected. The results obtained are analyzed with reference to RSG data.

The structural testing has been carried out on CFC Wing on Full-Aircraft in a floating testrig. During the multi-directional loading, the sum of forces and moments reach to near zero values and the landing gear attachment points to the test rig is almost free. In this configuration, the aircraft literally floats with a small load of less than 100kg for a structural test load of 75000 kg. The key issues of full aircraft loading, challenges in choosing the test load points, accessibility and implementation of overall balancing and loading schemes are explained. The wing is embedded with four identical FBG arrays, each containing eight FBGs with different Bragg resonance wavelengths. The critical locations of sensors are chosen based on the FEM and wing test strain results. The FBG data obtained have been found to be in good agreement with FEM and RSG data.

The Extrinsic Fabry–Perot Interferometer (EFPI) sensor has been used to measure the force on the control-rod on a flying aircraft. The effect of airspeed, flight maneuvers, altitude, temperature, and flight instrumentation issues are clearly described. In this case also, the comparison between the EFPI and RSG data has been made and found to be in good agreement.

To conclude, fiber optic sensors are being potential candidates for various applications, including structural and flight testing of aircrafts. However, their actual deployment in aerospace applications has not become popular due to issues such as bonding, cost of interrogations systems, the lack of real-time validation, etc. The present thesis has attempted to explore the feasibility of adaptation of two types of fiber optic sensors, namely FBG and EFPI sensors in real-time structural testing of aircraft components and full aircraft in ground as well as in flight. The design and development of three different test rigs, namely flexible test rig, fixed test rig and floating test rig, have been carried out under realistic structural loading conditions, to compare the influence of test article installation schemes on test data. The results obtained are compared with FEM data and those obtained from conventional sensors like displacement gauges and RSG. These results are found to be in good agreement, validating the deployment of fiber optic sensors for aerospace testing applications.