MANUFACTURING PROCESS OF SENSOR INSTALLATION COMPOSITE WING BOX

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1 Introduction

Structure health monitoring (SHM) system can monitor events in airframes such as load, impact and damage. It needs to install the sensors like fiber Bragg grating (FBG) sensors or lead zirconate titanate (PZT) sensors in the structures. In order to detect damage in composites aircraft structures, various sensors are required and should be tested to verify their sensitivities to detect damage under external influence. This paper introduces the manufacturing process of sensor installation on the fiber reinforced composite wing box as one of activities to develop an SHM development system. Sensor-installed composite wing box was fabricated carbon/epoxy materials and the three kinds of sensors were installed based on their roles, the low speed FBG (L-FBG) sensors for flight load monitoring, the high speed FBG (H-FBG) sensor for impact monitoring, and PZT sensor for damage monitoring. It was observed that the wing didn't have any permanent deformation under the static test conditions. The sensors installed composite wing box was evaluated during structural tests and the results of the study would be references for the development of the next health monitoring system of composite structures.

2 Manufacturing Composite wing box for performance test and sensor installation

2.1 Design of composite wing box

Sensor installed composite wing box was designed to develop a structural health monitoring system in UAV (unmanned aerial vehicle). The wing structure is a cantilever beam type consisting of two sections: the supporting section to support the whole structure and the loading section to put weight on the structure. The sensor installed composite wing box has a box beam consisting of skins, spars and ribs, while the supporting section which has a fitting lug designed to endure ultimate load and 3G. 1260mm(width) x 2340mm(length) x 250mm (height) dimension of composite wing box was fabricated using WSN3K & USN175BX (from SK Chemical) Carbon/Epoxy prepreg and AL7075-T7351 aluminum referring delta wing of aircraft. The upper skin was assembled by co-curing and lower skin was done by hardware fastening. Total weight of SICWB is 64.5kg. Figure 1 shows layout of the sensor installed composite wing box.

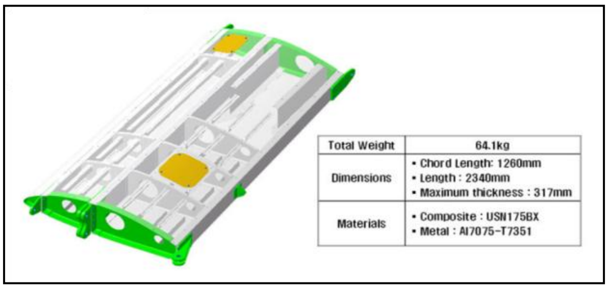

Figure 1 layout of the SICWB

2.2 Analysis of composite wing box

Stress analysis for composites structure was performed in order to define the sensor location which detect signal efficiently. Finite element model of the structure consists of 39,849 nodes and 31,630 elements and six kinds of isotropic materials and two kinds of orthotropic materials. 13kn of load were applied at the end of wing bracket and the boundary condition constrains the all DOF (degree of freedom) of wing root except spar rotation. Figure 2 shows Von-Mises stress distribution of the wing structure. This analysis showed the maximum stress occurred in the main wing root area between the intermediate spar and the fuselage. The high stresses were distributed following the middle spar. This result contributes where the sensor should be located for fine detection.

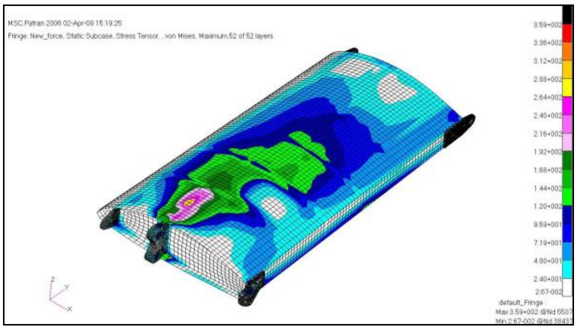

Figure 2 Stress analysis results of composite wing box

2.3. Sensor installation technique

Although a FBG sensor is easily embedded in the composite structure without mechanical degradation, it has a possibility of birefringence which supply wrong signal. In order to minimize the birefringence, it is required to embed FBG sensors between two 0° layers in the composite, which is not available for normal lay-up patterns. Our research led to a new method of embedding FBG sensor with minimized birefringence, making it possible to apply to normal lay-up patterns as well. In addition, we developed a surface installed technique for FBG and PZT sensors, and verified the installed and durability through fatigue tests.

SHM system use strain data from L-FBG sensors for flight load monitoring. 52 L-FBG sensors were installed inside of spar cap. And 14 strain gages were installed next to L-FBG. The data from strain gage and L-FBG sensor were compared for reliability of L-FBG sensors during the static load test.

2.4 Sensor integrated wing structure assembly

All assemblies of integrated wing structure have been bonded at room temperature. Sensor lines were aligned without interference each other and the structures. Fragile FBG sensors were protected by epoxy adhesives and the optical fibers were fixed to prevent the signal interference. The PZT sensor should be grounded and the senor in the composite could supply the signal. Identifications were numbered for each sensor line to prepare for sensor repairs and wiring changes. After installed of sensors, we checked the signal to confirm whether they are operating or not.

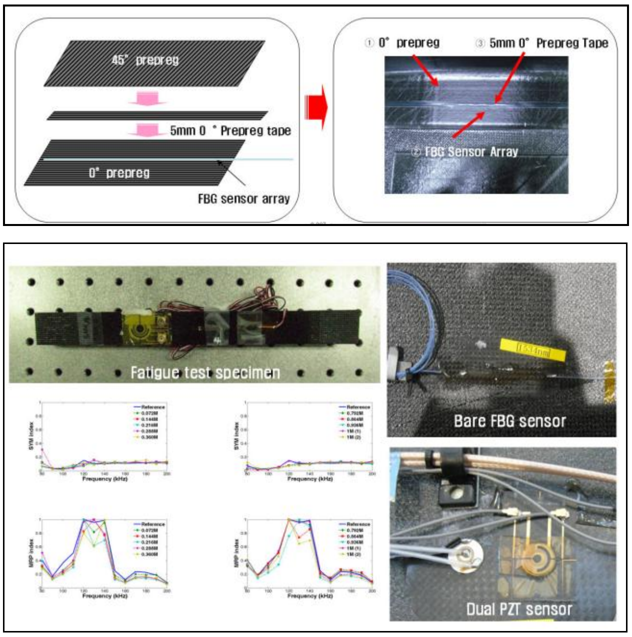

Figure 3 Sensor installation techniques.

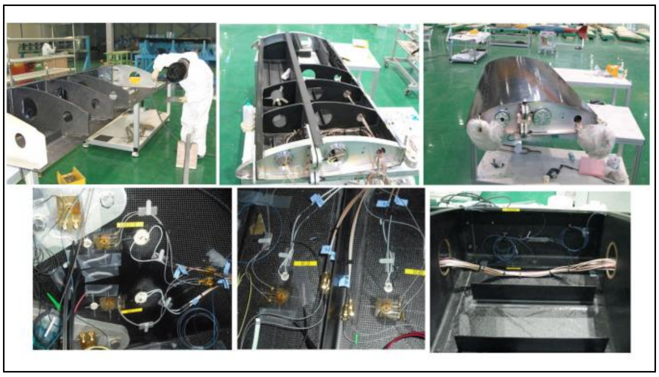

Figure 4 Sensor integrated wing structure assembly

3. Design of monitoring sensor

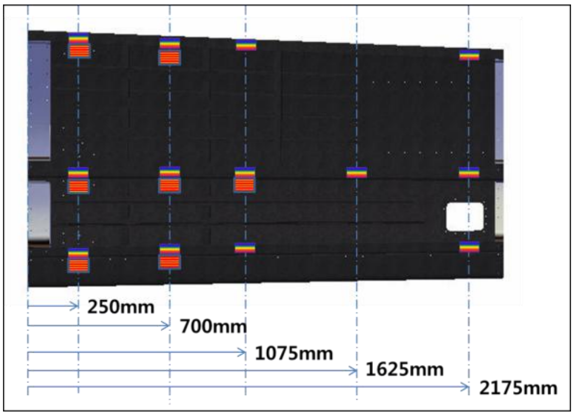

Figure 5 Location of L-FBG & Strain gage

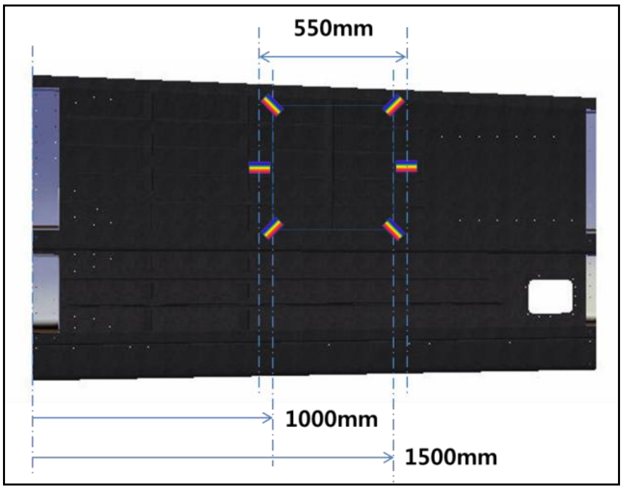

Figure 2 Location of H-FBG

3.1 Flight load monitoring sensor

Flight load were detected by L-FBG sensor through optical fiber and 26 of L-FBG were attached with three optical fiber. The location of 13 sensors was determined by stress analysis results.

3.2 Event monitoring sensor

H-FBG sensors were used for impact monitoring like foreign object damage (FOD), hail stone (six sensors in upper skin) and bird strike (four sensors in leading edge). Six of H-FBG sensors were attached inner of upper skin. The reliability of H-FBG sensors were secured during low-velocity impact test and bird-strike impact test. The square monitoring are were consist of 6 sensors and adhered with ±45˚ due to the optical fiber.

3.3 Damage monitoring sensor

SHM system used the impedance data of PZT sensor for damage monitoring like delamination, crack and bolt-loosening. Eight of PZT sensors were fixed inside of upper skin, spar and aluminum lug. The reliability of PZT sensors were secured for the static load test under the elevated temperature test.

4.Realiability of FBZ sensor

4.1 L-FBZ Sensor

Strain signals of L-FBG sensor were used to monitor the load during the flight. The FBG sensor on composites structure should be verified linear response due to load. Static test were performed with three rugs which were fixed. 6500N of load were applied at the end of the wing and the L-FBG signal were monitored. The signal were linear to load and tendency were same with strain gage. The various load application result could be used for developelemt of load monitoring algorithm.

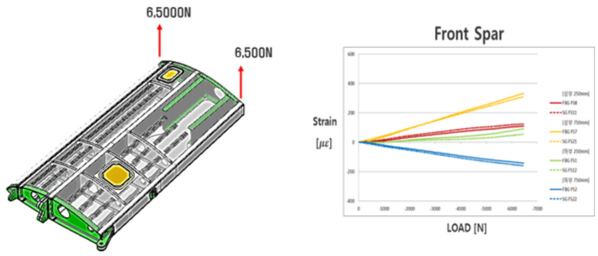

Figure 7 Compared sensor signal (Front spar L-FBG & Strain-gage)

4.2 H-FBZ Sensor

H-FBZ Sensor notice the estimated location of impact. The previous method which is calculated by signal arrival time could have error due to anisotropic composites charcters and structural interference. Newral network algorithm were applied in order to solve them. The response from impact data should be collected with consistance for credit. Low-speed impact test which keep constantly impact on consequence point were veryfied the consistance pattern of signal.

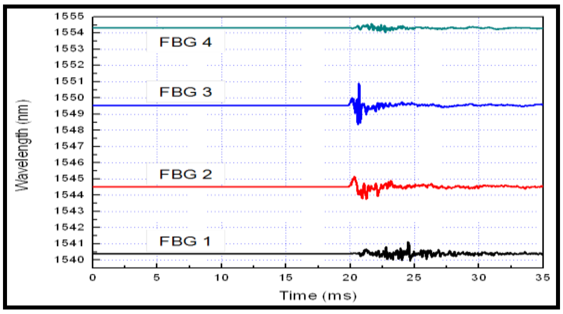

Figure 8 Impact signal of H-FBG

4.3 PZT Sensor

When the structures were damaged, the structural stiffness were changed and PZT sensor detect this by impedence signal. PZT sensor monitored the releasing the bolts and the the impedance signals were response at specific frequency. And it comes back when the bolts were fastened.

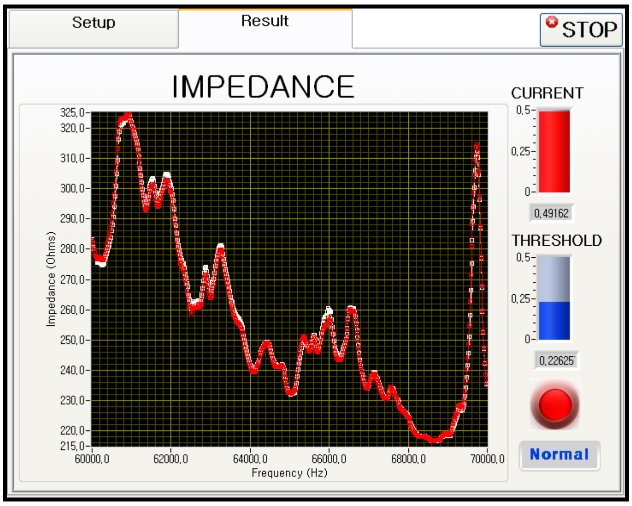

Figure 3 Impedance Signal of PZT

5 Conclusions

We developed a sensor installation composite wing box which was integrated FBG and PZT sensors. The numbers and locations of installed sensors were designed based on structure analysis, and tested through experiments. Some FBG sensors were embedded to minimize the birefringence. L-FBG sensors for load monitoring showed the linear response with loads and the reliability was confirmed by comparing with strain gauges. H-FBG sensors for detecting external impact were verified through low-velocity impact tests. PZT sensors monitored the defect by bolt-loosen tests. There was no permanent defect in the composites wing box under 13kN of static load and 8J of impact energy. And the sensors were notify exact position of the impact and able to detect damage in the structure.

Composites Structured Wing Box for will be exhibited in the ICCM18 show room and It could give a chance to demonstrate SHM system. The system (1000x1600x150mm) has 20 L-FBG sensors, 6 H-FBG sensors and 4 PZT sensors in order to monitor flight load, impact and bolt-loosen damage.

Figure 10 SHM demonstration system

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