Highly Reliable Advanced Grid Structure Proto-system for Aircraft Structures using Multi-point FBG Sensor

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KAZUSHI SEKINE, HAJIME TAKEYA, MASAMI KUME,

TSUYOSHI OZAKI, NOBUO TAKEDA, NAOYUKI TAJIMA

ABSTRACT:

Composite materials such as graphite fiber reinforced plastics are promising candidates to meet cost and weight saving demand in aircraft structures. However, since extremely high reliability is required for aircraft systems, composite materials have not been fully applied especially in commercial aircraft. A structural health monitoring system is the most effective technology to meet this requirement. The authors have been developing a new lightweight composite grid structure equipped with a health monitoring system utilizing FBG (Fiber Bragg Grating) sensors for aircraft applications. A grid structure, comprising multiple interconnected ribs in a truss-like arrangement, has a very simple path of stress, which is easily detected with FBG sensors embedded in the ribs.

In this report, fabrication and test results of HRAGS proto-system which was composed of HRAGS panel and FBG monitoring system were described. The size of the HRAGS panel was 525×540 mm. The number of embedded FBG sensor was 29. The skin panel was attached to the grid structure. The ASE light source and the wavelength meter using the diode array were used to measure the Bragg wavelength of FBG sensors. The strain distribution of the panel was measured under compressive load conditions. The artificial damage in the skin panel of the specimen was successfully detected by comparing the strain distribution before and after the introduction of the damage.

Kazushi Sekine[a], Hajime Takeya[a], Masami Kume[a], Tsuyoshi Ozaki[a],
Nobuo Takeda[b], Naoyuki Tajima[c]
[a] Advanced Technology R&D Center, Mitsubishi Electric Corporation,
1-1-57 Miyashimo, Sagamihara, Kanagawa, 229-1195, Japan
Sekine.Kazushi@eb.MitsubishiElectric.co.jp
[b] Graduate School of Frontier Sciences, The Univ. of Tokyo,
Mail Box 302, Kashiwanoha 5-1-5, Kashiwa-shi 277-8561, Japan
[c] R&D Institute of Metals and Composites for Future Industries,
Bridgestone Toranomon Bldg., 25-2, Toranomon 3-Chome, Minato-ku, Tokyo
105-0001, Japan

1. INTRODUCTION

There is a growing demand for lightweight structures in aircraft systems for energy and cost savings. Composite materials such as CFRP are promising candidates that meet these requirements. Extremely high reliability is required especially in commercial aircraft, yet adequate advancements have not been made in weight savings through the application of composite materials to aircraft systems. A structural health monitoring system is one of the most effective technologies to resolve this issue.

The authors have continued with the development of Highly Reliable Advanced Grid Structure (HRAGS) with the aim of application of the same to aircraft [1]. HRAGS is provided with health monitoring functions that make use of Fiber Bragg Grating (FBG) sensors in advanced grid structures [2,3] which have been the focus of attention in recent years as lightweight structures, and is a new lightweight structural concept that enables lighter weight to be obtained while maintaining high reliability.

In this report, a fabrication technique to embed multi-point FBG sensors into advanced grid structures was studied, first. Then, to verify the health monitoring functions of HRAGS, a proto system comprising advanced grid structure panels embedded with FBG sensors, wavelength detectors and measurement software, was developed and tested.

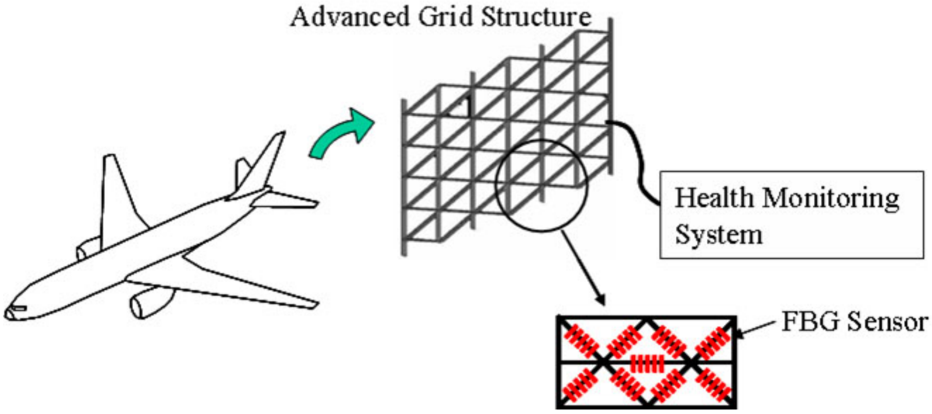

Figure 1-1 HRAGS Concept

2. EXPERIMENTAL METHODS

2.1 Method of manufacturing of HRAGS panel

Figure 2-1 shows the method of manufacturing HRAGS. As shown in the figure, HRAGS was prepared by laminating unidirectional tape pre-pregs sequentially in the 0°, +60°, and -60° directions. The width of the tape pre-preg was taken as 6 mm, and 34 layers were laminated to form a depth of approximately 10 mm. The size of the panel was 540 x 525 mm. The skin panel used had a quasi-isotropic configuration with unidirectional pre-preg material of thickness 0.5 mm approximately, and it was bonded to the grid panel after curing.

FBG sensors were disposed at the center of the ribs. FBG sensors were located at 9 to 10 points per optical fiber so that FBG sensors were arranged at a total of 29 points using 3 optical fibers. The wiring positions of the optical fibers in the height direction were between ply 1 and ply 2, between ply 2 and ply 3, and between ply 3 and ply 4 from the bonding face side of the skin material.

Using a six-axis computer controlled robot, automated lay-up of CFRP prepreg tapes and optical fiber was also studied here.

Figure 2-2 shows how the robot lays prepregs up in three direction of 0, 60, -60 degrees. By repeating such lay-up to make designed thickness, the substrate of a grid structure is to be obtained. An optical fiber with FBG sensors is also installed by this robot using another head.

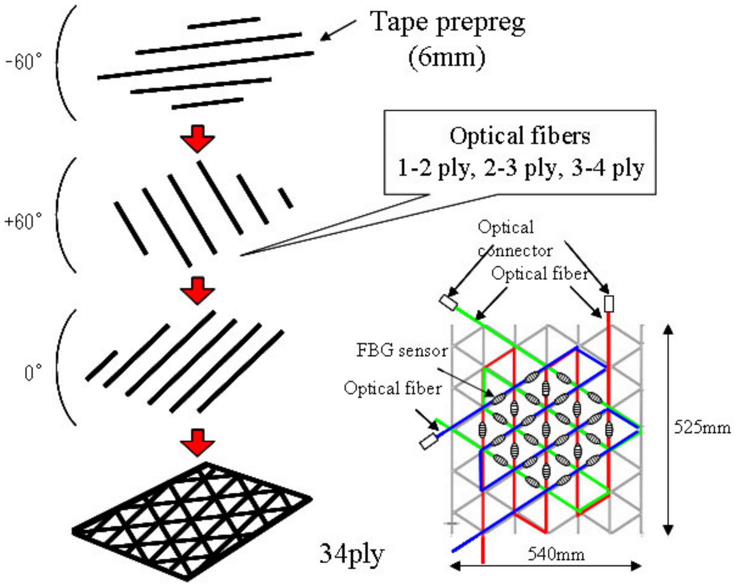

Figure 2-1 Manufacturing method

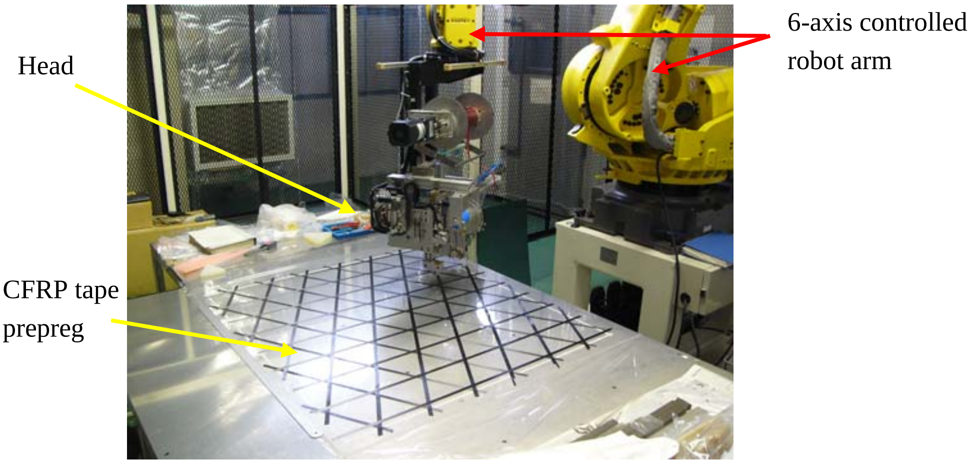

Figure 2-2 Automatic lay-up machine

2.2 HRAGS Proto System

Highly reliable AGS (HRAGS) features multipoint FBG sensor network embedded in the advanced grid structure. It enables distribution of strain occurring in the structure to be measured with the help of FBG sensors embedded at the center of each rib in the structure. If damage that is likely to become a problem in aircraft structure occurs, the strain distribution measured differs from the strain distribution when the structure is sound, and HRAGS can detect the damage and generate the alarm.

To realize a health monitoring system by HRAGS, it is necessary: 1) to read the wavelength information of FBG sensors embedded in HRAGS at high speed; 2) convert the acquired wavelength information into strain distribution; 3) compare the obtained strain distribution with the strain distribution of the structure in the healthy condition; and 4) assume damage has occurred if the change in strain distribution is greater than a fixed quantity and provide functions to display the position and change in the damage.

To realize such a system, the Proto System was developed comprising HRAGS panel, wavelength measurement system, and damage detecting software, as shown in Figure 2-3. As mentioned above, the panel is to be subjected to strain by applying a load on it for damage detection. Damage detection tests related to modes for applying compressive load in the in-plane direction of panels were carried out.

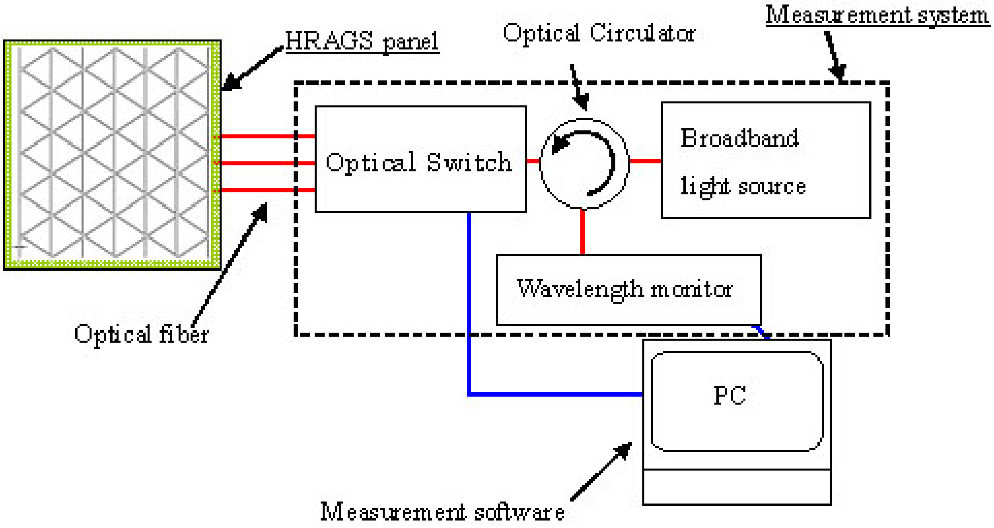

Fig. 2-3 Configuration of HRAGS Proto System

A photo diode array type wavelength meter capable of high-speed measurements (100 Hz) was used as the instrument for measuring wavelength and the C-band ASE module was used as the light source in the wavelength detection system. Since high speed likewise is obtained for switching over the optical path, MEMS-type optical switch with switching time of 10 ms was used. A personal computer was used for reading data from measuring instruments and for controlling the optical switches.

The strain distribution is compared with that in the healthy condition, and the difference is displayed graphically on the screen. The system judges damage to have been detected if the difference increases above a specific value, and emits an alarm.

3. RESULTS

Figure 3-1 shows the experimental set-up and the loading direction of compressive loads applied on the HRAGS panel. Marks at the center of the ribs in the figure indicate embedded positions of the FBG sensors. As shown in the figure, the damage was introduced almost at the center of the panel. To simulate and introduce damage, a hole was made at the center of the outer skin on the triangular part formed by the ribs. The diameter of the hole shown in the photograph is 40 mm.

With the experimental setup above, the strain distributions, when a compression load was applied, were measured before and after introducing simulated damage and these distributions were compared.

Figure 3-2 shows the measured results. The horizontal axis shows the rib numbers, while the vertical axis shows the difference in strain distributions in the healthy condition and in the condition when a damage was introduced. The rib numbers surrounding the damage were shown in Fig. 3-2. Note that the ribs with large difference in strain are the ribs surrounding the damage. In this way, the strains in the ribs surrounding the skin material in which the hole was introduced have changed, and the detection of damage was verified.

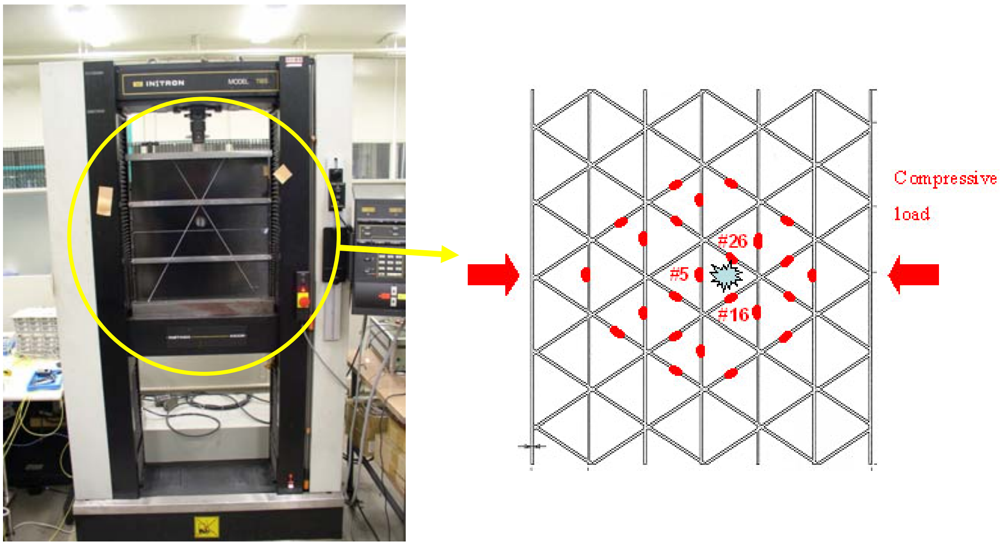

Figure 3-1 Experimental set-up

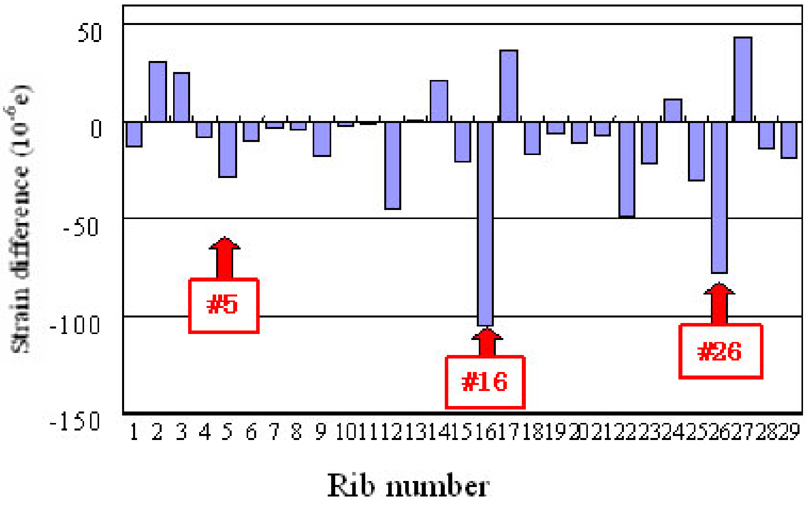

Figure 3-2 Difference in strain distributions and relationship between rib positions

4. CONCLUSIONS

The manufacturing method of HRAGS panel and HRAGS proto-system were developed and tested.

Simulated damage (hole in the skin material) was introduced in the HRAGS panel and the strain distributions before and after damage were compared. The results showed that damage detection is feasible and it was experimentally verified since the strain response of ribs surrounding the skin material with the damage varied significantly.

Henceforth, we propose to manufacture a 1x2-m scale demonstrator for aircraft structures using the technology described above.

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