HIGHLY RELIABLE ADVANCED GRID STRUCTURE DEMONSTRATOR

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Abstract

There is a growing demand for lightweight structures in aircraft systems for energy and cost savings. The authors have continued development of Highly Reliable Advanced Grid Structure (HRAGS) with the aim of application of the same to aircraft. To verify the effectiveness of HRAGS for aircraft members, detailed design of a wing tip demonstrator was performed, and confirmation of damage detecting ability and optical loss design was performed analytically. The wing tip demonstrator has Fiber Bragg Grating (FBG) sensors at about 600 points and a size of 1x2m. From studies on the differential strain distribution before and after the occurrence of damage in the analytical model, it was confirmed that damage detection was feasible. It was also verified from optical loss design that 40 of the multiplexed sensors required for realizing the 600-point FBG sensor network can be embedded without problems.

1 Introduction

There is a growing demand in recent years for lightweight structures in aircraft systems from the viewpoints of energy and cost savings. The authors have therefore continued development of Highly Reliable Advanced Grid Structure (HRAGS) [1], [2], with the aim of application of the same to aircraft. HRAGS is provided with health monitoring functions that make use of Fiber Bragg Grating (FBG) sensors in advanced grid structures [3], [4], and it has been the focus of attention in recent years as a lightweight structure. It is a new lightweight structural concept (Fig. 1) that enables lighter weight to be obtained while maintaining high reliability.

Using the HRAGS concept and multipoint FBG sensors embedded in advanced grid structure panels, strain measurements could be made [1] equivalent to those of strain gauges until now. Moreover, the damage detection function of the HRAGS Proto-system has been confirmed [2].

To verify the effectiveness of HRAGS for aircraft structures, design and manufacture of a wing tip demonstrator were started for simulating actual aircraft structural members. The verification of damage detecting ability from the analysis model and the detailed design of the demonstrator, including optical loss design of the FBG sensor network embedded in advanced grid structures are reported here.

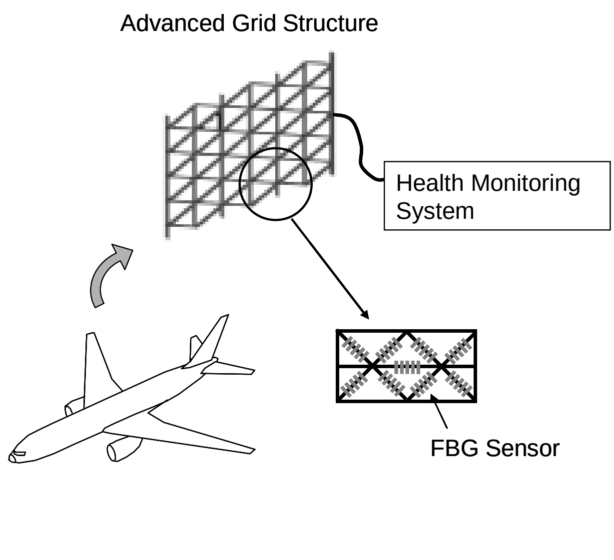

Fig. 1. HRAGS concept

2 Overview of the HRAGS demonstrator

The effectiveness of three-dimensional finite element model is verified, the expansion of actual structure including I/F structure between members to box structure is performed, the damage detecting ability in strain distribution analysis is confirmed, and the practical application of the detection system is verified using members simulating aircraft structures in the HRAGS demonstrator. The demonstrator is also used to verify the technology for mounting optical fiber sensor network (embedding of 600-point FBG) to the scale of actual aircraft structural members. Here, the wing tip was selected as the member to be studied and its design was performed. Fig. 2. shows the overview of wingtip demonstrator.

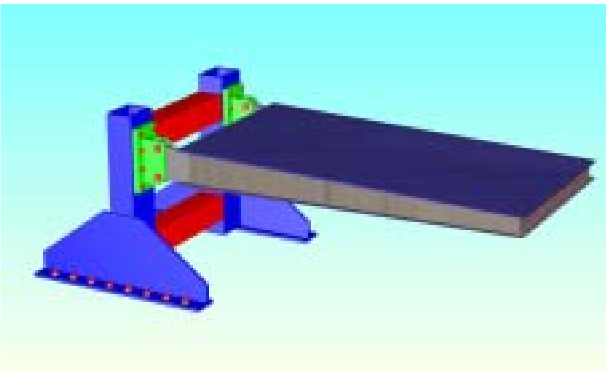

Fig. 2. Overview of wingtip demonstrator

3 Design of wing tip demonstrator

The wing tip is a member at the wing ends of an aircraft. Bending is the main deformation mode of the wing tip. For this reason, loads similar to those on the actual wing tip are assigned for tests on the demonstrator. Here, a cantilever beam test configuration was adopted wherein the root part of the blade was fixed in a jig, and the end of the blade was pressed by an actuator. The root part of the wing tip was fixed at two points in the jig.

Fig. 3 shows the model of the basic structure of wing tip for the demonstrator. The upper and lower surfaces and the side plating form a box structure comprising the ribs. The HRAGS panel is used in the skin panel of the upper and lower surfaces of the wing tip.

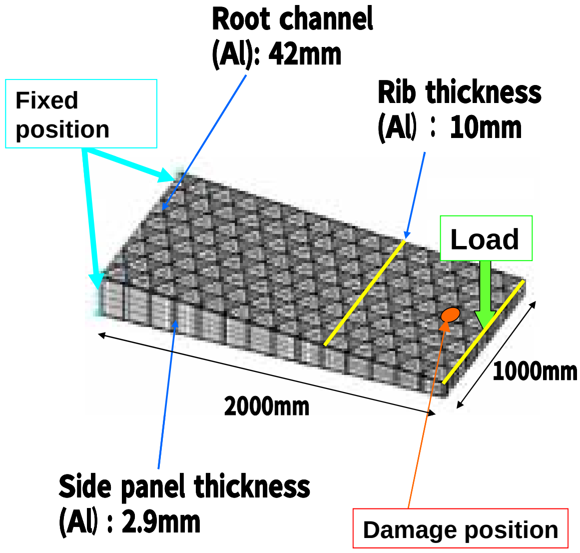

Fig. 3. Configuration of Wing-tip demonstrator

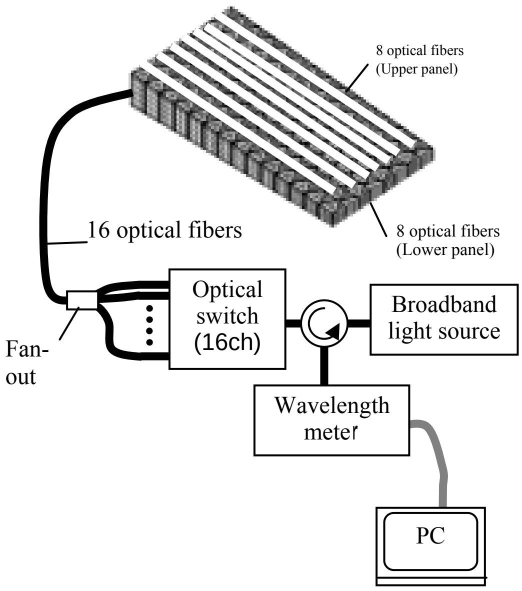

Fig. 4. Optical fiber sensing system

The dimensions of the model assumed were: width of 1 m, length of 2 m, thickness at the root of 0.2 m, and thickness at the tip of 0.08 m. The grid unit was in the shape of an equilateral triangle. The length of one side of the triangle was 145 mm. The grid configuration of the HRAGS panels on the upper and lower surfaces were 8 grids corresponding to a width of 1000 mm, and 14 grids corresponding to a length of 2000 mm. The rib orientation of the grid was taken as 0 degrees/ ±60 degrees assuming the longitudinal direction as 0 degrees.

The damage that has occurred to the skin panel was detected from the change after comparison of measured values of strain distribution corresponding to loads acquired beforehand when the panel was in a healthy condition and the present strain distribution. The FBG sensors for measuring strain were arranged at the center of the ribs in the grid in the HRAGS panel. Approximately 600 measurement points were disposed on all ribs of the upper and lower surface of the demonstrator.

The optical fiber system is a system in which FBG sensors are multiplexed at 40 points at a wavelength spacing of 1 nm per fiber. There are a total of 15 to 16 such systems that perform measurements while switching with optical switches.

Fig. 4 shows the configuration of the sensing system. To measure the wavelength signals from the 600-point FBG sensors at high speed, a photodiode array type wavemeter with sampling frequency of 100 Hz studied in the Proto-system [2] and MEMS type optical switch capable of switching optical paths at high speed were used.

4 Verification by analysis of damage detecting ability

In the HRAGS demonstrator, the damage that has occurred to the skin panel is detected by determining the change in measured values after comparing the measured values of strain distribution corresponding to loads acquired beforehand when the panel was in a healthy condition and the present strain distribution. If this change in the strain distribution exceeds a fixed value, a warning is given to the effect that damage has occurred. Here, the damage detecting ability was verified by using the analysis model shown in Fig. 3.

The strain sensitivity due to FBG sensor is of the order of several με. However, it was assumed that damage can be adequately detected if a strain distribution greater than 100 με is generated when a load is applied, considering the effects of temperature and humidity on the FBG sensors[5].

The loading condition assumed was loading point at the blade end, and the maximum load applied as 2500 kgf approximately.

For this loading condition, simulated damage was introduced in the skin panel, and the strain distributions before and after introducing the damage were compared. Damage was assumed when a hole occurred in the skin panel.

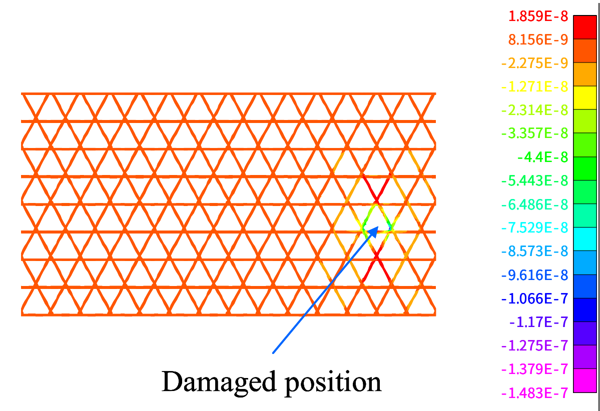

Fig. 5. Differential strain distribution generated in the grid

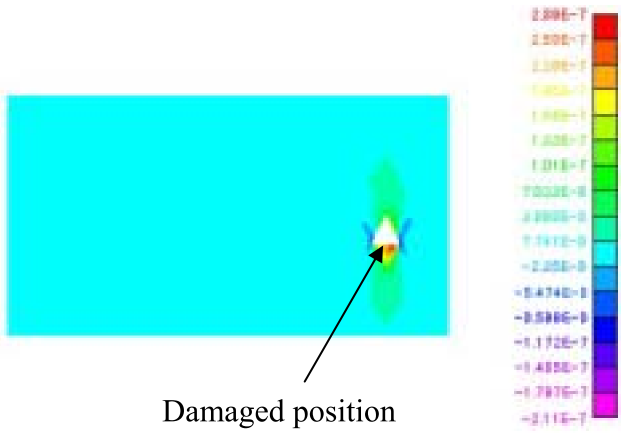

Fig. 6. Differential strain distribution generated in the skin

Fig. 5. shows the differential strain distribution generated in the grid when damage is introduced at the center of the 13th grid counting from the root side by loading (1 kgf) a concentrated load at the blade end. The differential strain distribution generated in the skin panel shown here is similar to

that in Fig. 6. From these results, it can be observed that when the load exceeds 2150 kgf, the differential strain generated due to the damage becomes 100 με. The load lies within the range of the loading condition, and the result thus confirms the damage detecting ability.

5 Study of load addition method

The method of using a loading jig so that external load is applied uniformly was considered as the method for applying external load in the demonstration for damage detection of the wing tip full scale model. The characteristics required for this jig are the ability to transfer stress uniformly to all contact surfaces holding the blade, that is, it should have adequate rigidity (higher rigidity than the HRAGS panel), and should have small deformation corresponding to the test load. As shown in Fig. 7, the configuration adopted C-channels for members that hold the blade from the top and the bottom, and plates at both ends that connect the upper and lower channels, with an I/F member for load input fitted at the center of the channel on one side.

From the analysis results, after implementing damage detection and evaluation, it was verified that the C-channel configuration with aluminum used as the material of the channel with a thickness of 5 mm, height of 64 mm and width of 32 mm, has adequate rigidity to take up adequately the uniform strain distribution on the HRAGS panel.

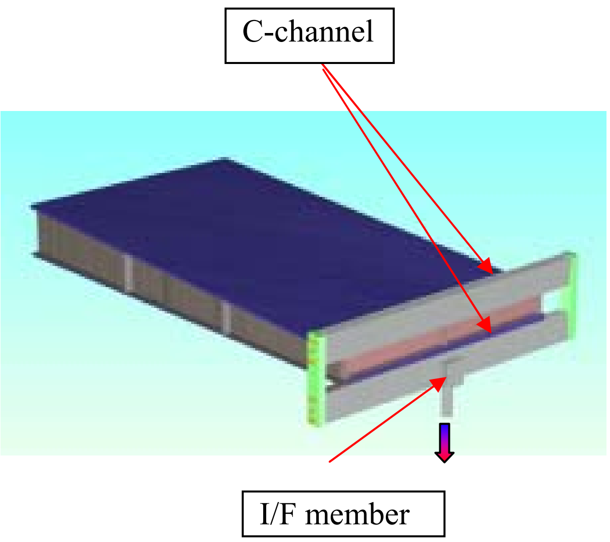

Fig. 7. Load addition method

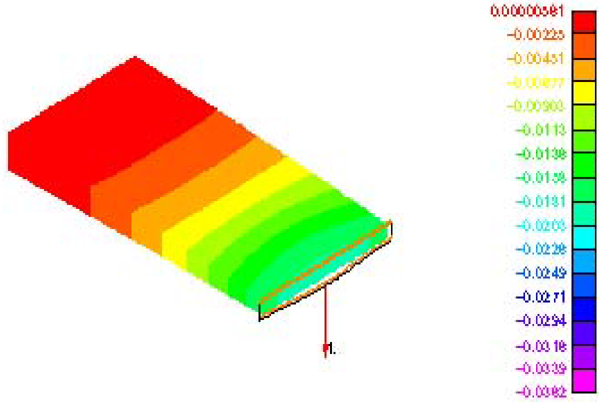

Fig.8. Analysis results

6 Optical loss design

To measure the Bragg wavelength of FBG sensor embedded in HRAGS, the variation in optical loss between the sensors should be within the range of measurement of the measuring instrument, and should preferably be below 15 dB. A prototype of the HRAGS panel of size 1 m x 1 m was made, and the optical loss generated in the demonstrator was estimated.

Figure 9 shows the grid pattern of the HRAGS test specimen, and the positions of the optical fibers embedded in it. The grid size of the test specimen is 167 mm and the rib width is 12 mm. In the figure, the squares indicate the positions of input/ output connectors, while the circles indicate positions of FBG sensors. Optical fibers pass through all 18 grids. FBG sensors are arranged in 14 of these grids. Figure 10 shows the number of grids from the optical inputs/ outputs, and the insertion loss of Bragg wavelength of the FBG sensor. From the figure, no clear increase in loss due to the curved points inserted in the multipoint FBG sensors was observed. From the above, it was concluded that loss is negligible when a 120-degree curve is made for a rib width of 12 mm.

Next, the optical loss in the transmission line is proportional to the distance from the input/ output ends. From the approximation line in the figure, its gradient was found to be 0.3 dB/ grid.

Based on these results, the optical loss generated in the wing tip demonstrator was estimated. The maximum number of FBG sensors installed in one optical fiber is 40. Assuming that 7 blank locations in the grid are to be passed through during wiring, the deviation in loss is 12.3 dB, so even if the HRAGS size is 1 x 2 m, sensors can be embedded without problems.

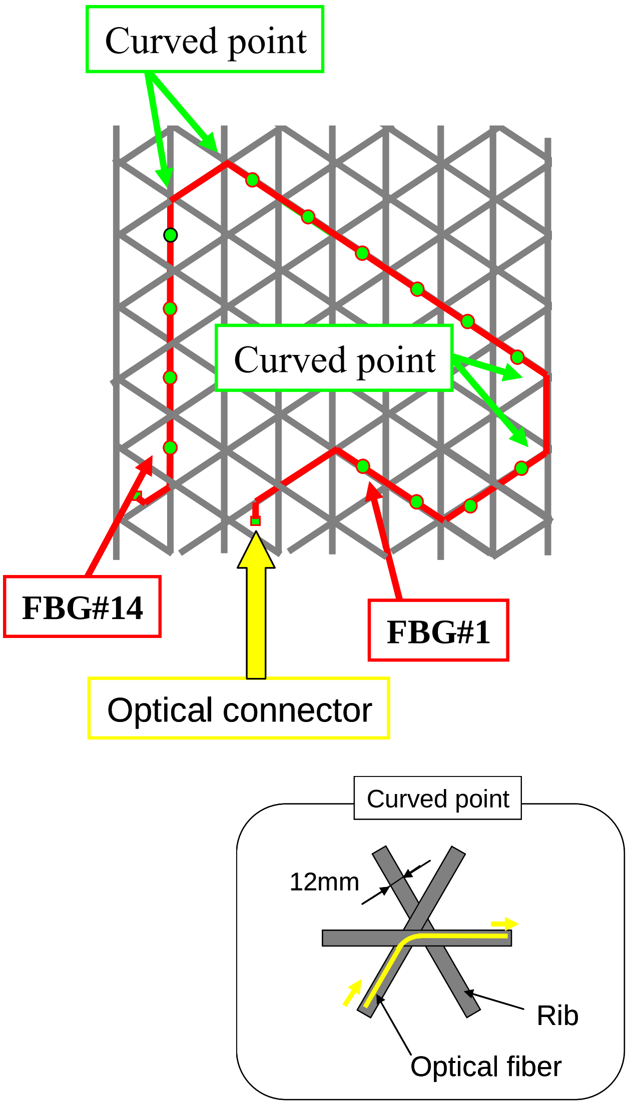

Fig. 9. Grid pattern of the HRAGS test specimen, and the positions of the FBG

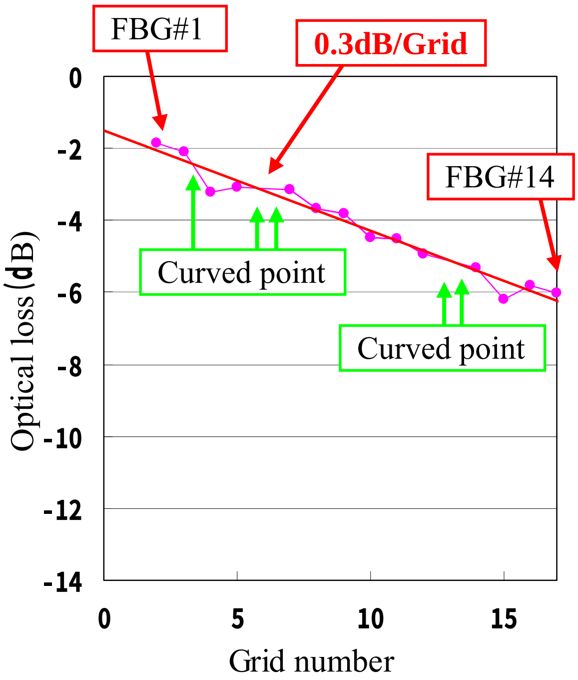

Fig. 10. Relationship between optical loss and grid number

7 Conclusions and future topics

To validate the effectiveness of HRAGS for aircraft members, detailed design of wing tip demonstrator using HRAGS was performed, the damage detecting ability by analysis was confirmed and optical loss design was carried out. The results confirmed that in a wing tip demonstrator configuration having FBG sensors at about 600 points of size 1 x 2 m, a differential strain of 100 με required for detecting the occurrence of damage by analysis model occurs within the scope of loading conditions. It was also confirmed after performing optical loss design that 40 of the multiplexed sensors required for realizing the 600-point FBG sensor network can be embedded without problems. The authors will henceforth manufacture and evaluate the demonstrator based on detailed design.

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