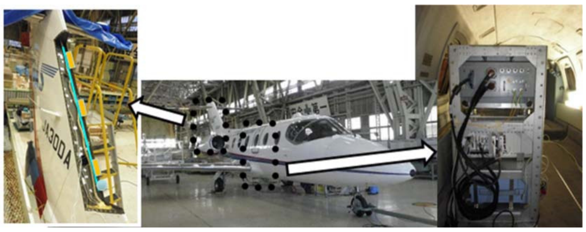
Cost Reduction Technology for Airframe Maintenance



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Recently, aircraft structures adopt a damage tolerance design and its airworthiness is maintained through the periodical inspections specified in the maintenance plan before it becomes fatal. The establishment of health monitoring technology to continuously monitor the condition and airworthiness of an aircraft structure will hopefully lengthen the present inspection intervals and reduce maintenance costs, thereby improving the efficiency of aircraft operation. The authors developed an optical fiber sensor-based system for wide-area diagnosis of aircraft structures and evaluated its applicability to adopt structure condition monitoring through flight demonstration testing. It was found that the developed system can monitor the structural condition during flight operation.

1. Introduction

In aircraft operation, shorter aircraft inspection intervals and lower monitoring costs are among the matters required for higher managerial efficiency. Accordingly, there is hope for the commercialization of a structural health monitoring (hereinafter abbreviated as SHM) system that can be substituted for the structural inspection of aircraft during operations.

A variety of approaches have been adopted to implement such a system and many researchers and engineers are striving for its commercialization. Among such efforts, the authors are engaged in R&D for the commercialization of the SHM system through the application of Brillouin optical correlation domain analysis (hereinafter abbreviated to BOCDA) technology to make wide-area diagnosis available with an optical fiber sensor that is light-weight, causes no electromagnetic interference, and is capable of being embedded into composite material.

BOCDA can characteristically measure distributed strain along the entire length of an optical fiber and dynamic strain at arbitrary points. **Figure 1** shows a conceptual image of its application to the SHM system based on such characteristics. The evaluation of optical fiber sensors placed across the airframe structure is now designed to identify the fatigue damage/structural life through the monitoring of damage occurrence due to changes of distributed strain or the measurement of dynamic strain.

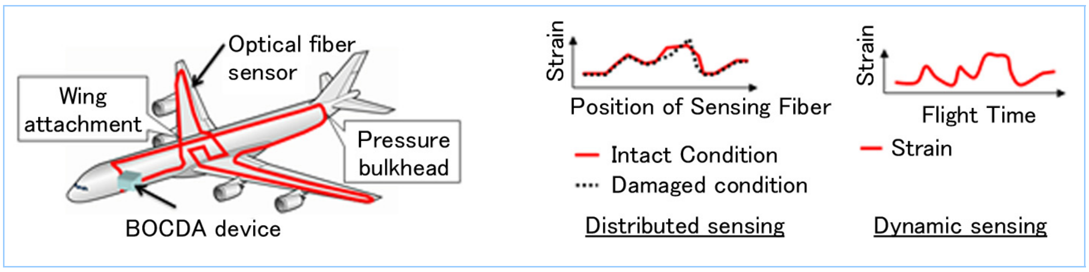

Figure 1 SHM System Application Concept

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Using distributed optical fiber sensors, technology has so far been developed to detect de-lamination and other damage in the aircraft composite structure.[1] In this R&D, a BOCDA measurement system that can be mounted on an aircraft was developed/prototyped and, in tests for flight demonstration, its applicability to damage monitoring during operations was checked.

2. Development of BOCDA-SHM system

One of the features of BOCDA is the ability to measure distributed strain along the entire length of an optical fiber and dynamic strain at arbitrary points. The following is a summary concerning the principle of BOCDA measurement and the development of a BOCDA measurement system that can be mounted on an aircraft.

2.1 BOCDA measurement principle

BOCDA is technology to measure the optical fiber's strain/temperature in light of the Brillouin scattering phenomenon that occurs within the fiber. Two opposite laser light inputs, with one referred to as a pump light and the other a probe light, can acquire Brillouin scattering light at arbitrary (correlation) points of an optical fiber through frequency modulation under certain respective conditions.[2]

Since the Brillouin scattering light frequency changes in proportion to strain and temperature, it is necessary in measuring the strain of an aircraft structure to measure the structure's temperature at the same time. Here, however, it becomes possible to simultaneously measure the optical fiber's strain and temperature if polarization maintaining fiber (PMF) is used as the optical fiber and changes in not only PMF birefringence, but also Brillouin scattering light frequency, are measured.[3] **Figure 2** diagrams the measurement principle. Pump light and probe light are admitted into the X axis of a polarization maintaining optical fiber to acquire the Brillouin scattering light frequency, and read-out light is admitted into the Y axis of the fiber to acquire BDG (Brillouin Dynamic Grating) frequencies that change in proportion to the birefringence of the optical fiber. Since Brillouin scattering light frequency changes and birefringence changes are different physical phenomena, strain and temperature can be calculated from these changes.

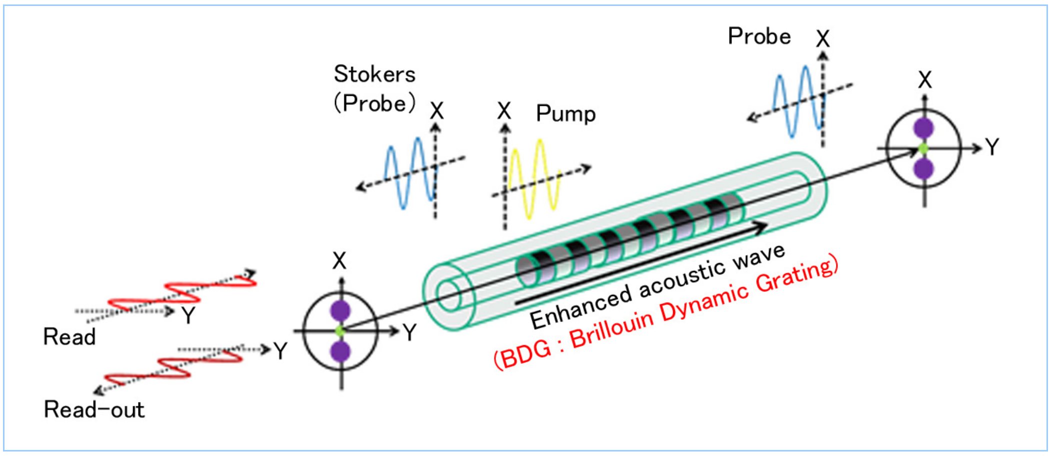

Figure 2 Brillouin Scattering Light Measurement Principle

2.2 Airborne BOCDA system development

The BOCDA measurement system to measure distributed/dynamic strain and temperature with an optical fiber sensor was prototyped as a device that can be mounted on an aircraft. Since compliance with Avionics Installation Standard ARINC600 makes it easier for it to be mounted on business aircraft, an interfaced system installable on a rack conforming to ARINC600 was manufactured on a trial basis (**Figure 3**). The prototyped system, driven by a DC28V power supply, is 388mm-wide, 193mm-tall and 412mm-deep, and weighs 14kg.

Figure 4 shows the result of measurements based on an optical fiber along the length of which temperature increase sections of about 4m and 1.5m were arranged together with an applied strain section of about 1m. Although strain/temperature measurement errors appear at both ends of the applied strain section, they are noise resulting from the difference in the measurement section of Brillouin scattering light from birefringence, and can be removed. In addition, tests for the evaluation of durability against the airborne environment were conducted, finding normal operation in such an environment. **Table 1** relates the results of environmental durability evaluation tests and **Figuer 5** shows how durability tests were conducted.

Figure 3 Outside Appearance of SHM Device

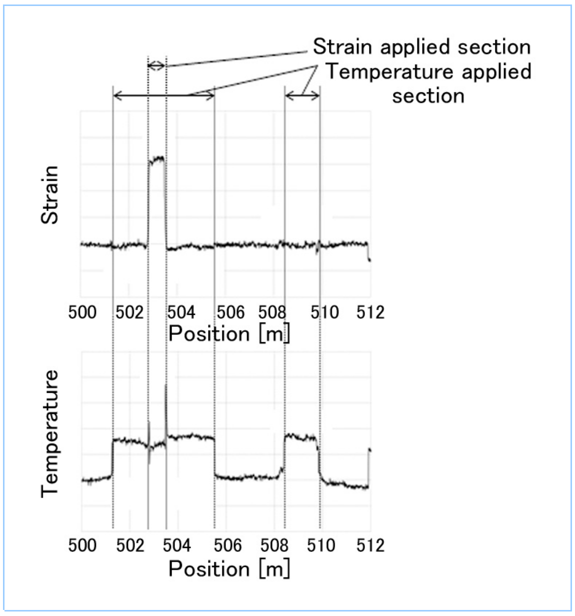

Figure 4 BOCDA Measurement Separation of Strain from Temperature

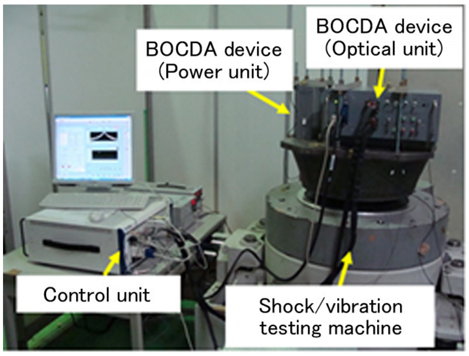

Figure 5 State of Environmental Durability Tests

Table 1 Environmental Durability Evaluation Test Results

No.	Item	Specifications	Result
1	Vibration environment	10—2000Hz, 0.74G (RTCA-DO-160 Category S2)	No equipment failure
2	Shock environment	6G, 11ms (RTCA-DO-160 Category A)	No equipment failure
3	EMI	Mutual influence with airborne flight testing apparatus installed to be evaluated	Normal operation

3. Flight Demonstration Tests

3.1 Test method

For flight demonstration tests, a business jet (an 11-seat MU-300 with a total length of 14.7m and a total width of 13.7m) was used as the test bed. With an optical fiber sensor bonded to the vertical tail plane's front spar of the test bed and connected to an airborne BOCDA measurement system installed in the cabin, strain and temperature were measured during flight. **Figure 6** shows the installed states of the sensor and the BOCDA measurement system.

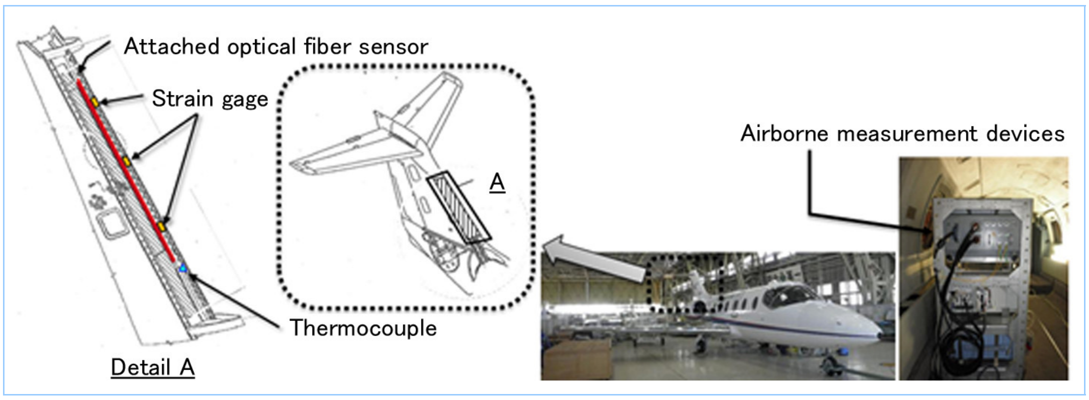

Figure 6 Installed State of Airborne SHM System

Strain/temperature measurements from the aircraft structure with a BOCDA measurement system installed on the test bed were taken during take-off climbing, level flight, and turning. Measurements were taken focusing on dynamic strain and temperature changes during take-off climbing, distributed strain and temperature distribution during level flight, and strain changes during turning.

3.2 Test results and discussions

Figures 7 through **9** show the result of measurements during take-off climbing, level flight, and turning. In the take-off climbing case (Fig. 7), it is found that a decrease in structural temperature with climbing has been successfully measured. From around 700 seconds, where the temperature sags below zero, however, a difference from conventional measurements starts to occur. Due to the bonded optical fiber sensor's tortuosity and for other reasons, it is possible that compressive structural strain may not be properly conveyed to the optical fiber. During level flight (Fig. 8), strain and temperature distributions present almost the same values as conventional measurements. In the case of turning (Fig. 9), good agreement with conventional measurements was achieved, and therefore, the measurement function is found to be sound in the actual operational environment.

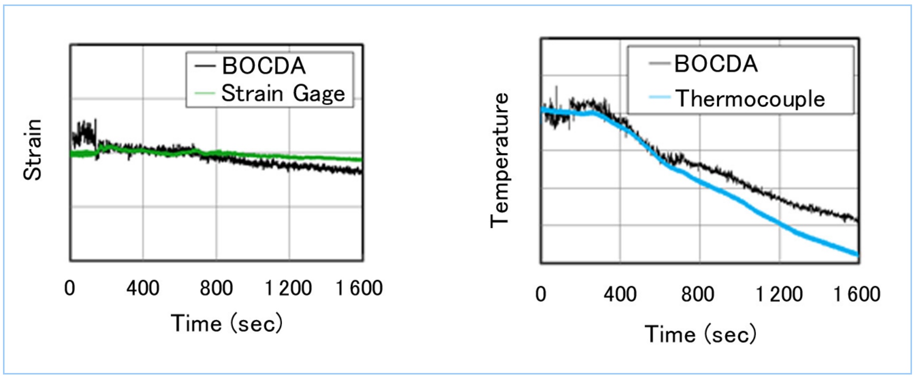

Figure 7 Result of Demonstration Tests (During Take-Off Climbing)

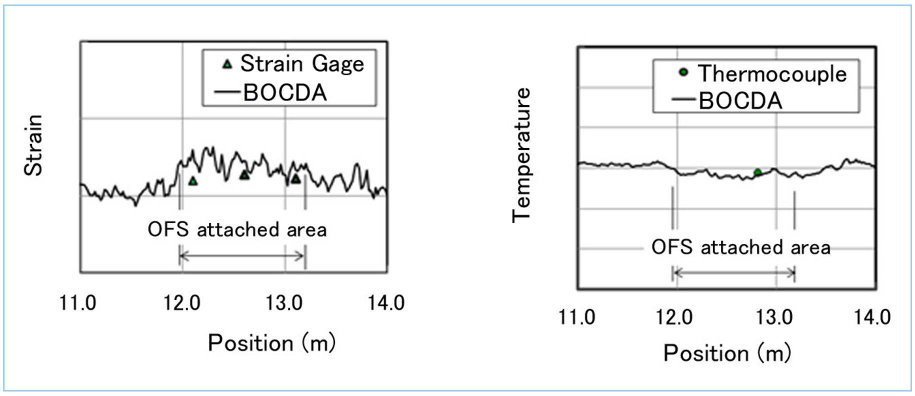

Figure 8 Result of Demonstration Tests (During Level Flight)

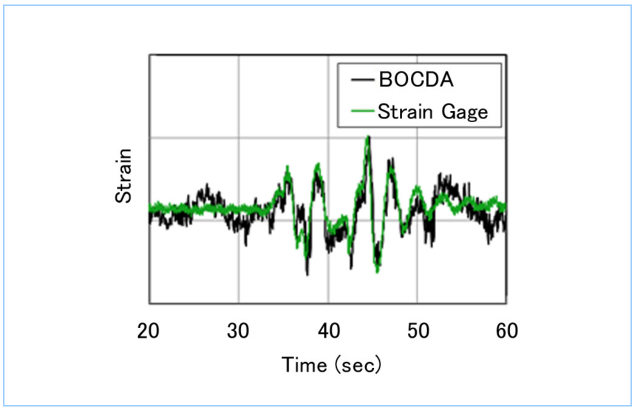

Figure 9 Demonstration Test Results (Turning Case)

4. Conclusion

As part of demonstration tests for the commercialization of an aircraft structure diagnostic system, strain and temperature changes in the aircraft structure during aircraft operations were measured. The following results were obtained:

- A BOCDA measurement system complying with the standard for installation on business aircraft and able to endure the installed environment was prototyped.
- It was shown that strain and temperature of an aircraft structure during flight can be monitored, but accuracy in the low temperature range needs to be improved.

Henceforth, development efforts are to be made for the commercialization of BOCDA measuring equipment such as through the improvement of its measurement accuracy, an evaluation of its application to structural inspection for cost advantages, certification planning, and conformity assessment. Finally, this work was conducted as a part of the “Aerospace Industry Innovation Program – Advanced Materials & Process Development for Next-Generation Aircraft Structures” project under a contract with The Material Process Technology Center (SOKEIZAI Center), founded by the Ministry of Economy, Trade and Industry (METI) of Japan. We hereby express our gratitude to everyone involved.

Reference

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