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Application of Fiber Bragg Grating Sensor Technology for Aircraft Composite Structures Health Monitoring

Xing Liwen

Mianyang Sub-college, Civil Aviation Flight University of China, Mianyang 621000, China

Email: xingliwen@126.com

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Abstract: The character of fiber Bragg grating sensor technology is expatiated briefly. The main introduction and analysis are made according to the time sequence and different categories according to the application of aircraft composite structures health monitoring. Finally, makes a number of recommendations on its future research and research direction of prospect.

1. Introduction

Composite material has many advantages, such as high specific strength, high specific stiffness, fatigue strength, corrosion resistance, etc. The content of composite has become one of the standards to measure the advanced of the aircraft. However,with the extensive application of composite materials in aircraft structures, some faults are highlighted as disbond, delamination, damaging ,even fracture with the impact loading. Therefore, continuous monitoring of aircraft is used of the structure status. The conventional nondestructive testing methods taking on composite are offline and static detection methods, such as X ray, ultrasonic, c-scan, infrared thermograph and acoustic emission, and etc. Those methods are unable to make timely response to the real-time situation of the structures. The structural health monitoring technology using sensors embedded on the surface of the structure or the internal structure to detect the changes of the structure itself and the external environment can achieve real-time online monitoring and judge the sudden damage of the structure. Structural health monitoring technology has the advantages of real-time online detection of structural state, automatic data acquisition and processing, reasonable design of detection structure. Compared with the traditional offline detection method, FBG has been gradually applied in aircraft with strict requirements for safety.

The sensors in aircraft are arranged closely which has high requirements for the volume, weight and sensitivity[1]. A large number of sensors arrange in order to monitor pressure, temperature, vibration, fuel level and rudder position. Therefore, the weight, size and inerrability of sensors are very important. Piezoelectric ceramic sensor is commonly used in traditional structural health monitoring system to continuously monitor the structure. This type of sensor has the advantages of high sensitivity, reliable technology and low price, but it is usually large in size, not compatible with the matrix of composite material and difficult to be implanted in the composite structures. As a new type of sensor element, fiber Bragg grating sensor although not as accurate as piezoelectric ceramic sensor in detection accuracy, with the advantages of small size, high compatibility of composite matrix and easy implantation, and gradually considering as an ideal component for composite material health monitoring.

2. Principle and advantages of FBG

Working principle of fiber Bragg grating sensor is shown in figure 1: first of all, broadband source incident the optical signal with a certain bandwidth into the fiber Bragg grating through the circulator. Based on the characteristics of fiber Bragg grating wavelength selection, suitable light is reflected back again through the circulator into the demodulation devices. Finally, the wavelength change of the FBG is detected in the demodulation device[2]. The fiber Bragg grating sensor is used

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as the detection element to measure the external temperature, pressure or stress, the grating pitch changes, so as to change the wavelength of reflected light correspondingly. The demodulation device calculates the value of external temperature, pressure or stress by detecting the wavelength change.

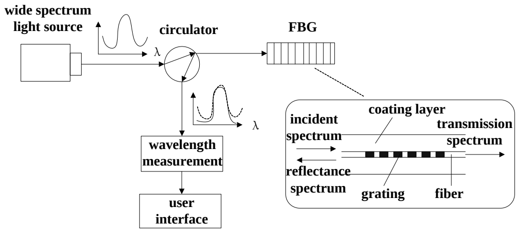

Fig.1 the principle of FBG

Fiber Bragg grating sensors, as the main components of aircraft composite structure health monitoring, have the following advantages [3]:(1)small size (common optical fiber outer diameter 250μm, the smallest sensor optical fiber diameter 35-40μm), light weight, variable shape, easy to implant with little impact on the structure;(2)well compatibility with composite matrix and transfer load effectively;(3)the sensing signal is wavelength modulated, which is quite insensitive to the system loss caused by the power fluctuation and micro-bending of the light source, etc. The sensor has strong reliability and stability, strong anti-interference ability, and can work in harsh chemical environment or electromagnetic interference environment;(4)the main component of the optical fiber core is SiO_2, which can withstand high temperature;(5)the measurement uses light transmission with high sensitivity and fast reaction speed;(6)distributed sensor network which made to multi-point measurement of a large area and detect multiple parameters at the same time through multiplexing technology, so as to realize long-term monitoring of key areas. (7)low maintenance cost.

3. Application of FBG on aircraft

Fiber Bragg grating sensing technology was first proposed in the United States and relevant application research was carried out. In 1979, NASA carried out a fiber optic astute mechanism and aircraft skin project[4], in which fiber optic sensors were embedded into polymer matrix composite skin to monitor the strain and temperature variations of composite structure. In the 1980s, the university of Hampton and the Langley research center of NASA applied fiber Bragg grating sensors to monitor the aerodynamics device to distinguish the wavelength shift of grating reflection caused by temperature and shear stress which is the preliminary exploratory study on the application of fiber Bragg grating sensing technology in aircraft. Into the 1990s, the U.S. military used the optical fiber sensors to monitor the torque of wing spar in the fatigue test of F/A-18 plane bulkhead first, and then implant sensors in the F-18 fighter vertical stability for confirmatory test of health monitoring which implement the optical fiber sensing technology in the practical application of aircraft composite structure breakthrough. Subsequently, the F-18, F-22, F-35 and other fighters with large consumption of composite materials were all embedded with fiber Bragg grating sensor network in the fuselage, wings and other important parts for dynamic measurement of strain, temperature and other parameters and structural health monitoring. In 1998, NASA installed the fiber Bragg grating multidirectional strain and temperature measurement system on the X-33 prototype to conduct real-time health monitoring of the structure. Lockheed Martin has implant the fiber Bragg grating sensor network into the X-33 space shuttle to quasi-distributed monitoring stress and temperature .NASA plans to study multipurpose fiber optic sensors used in composite containers at room temperature and low temperature and Marshall space center conducted research on reusable carrier rockets and composite fuel tanks of Boeing and McDonnell Douglas. In 2001, German scientists put a set of 12 fiber Bragg grating sensors into a space distributed sensing network system to monitor the temperature and strain of the hull structure of the X-38 spacecraft, so as to test the reliability of its structure in the space environment. In 2010, NASA placed fiber optic sensor networks on the wing surfaces of an improved all-composite predator B drone which fully achieved real-time monitoring of structural integrity. In the first decade of the 21st century, other countries have also done a lot of work on the application of fiber optic sensors in the composite material of military aircraft. The French institute of optics, in collaboration with Thomson, used fiber Bragg grating sensors embedded in composite structures to detect invisible defects such as internal layering and degumming. The national program for intelligent materials, developed by the Swedish institute of optics, will develop fiber Bragg grating sensors to monitor multiple use strain and temperature measurements of composite aircraft structures and a further real-time health monitoring system for fighter load monitoring and damage detection. Indian scientists added 16 fiber Bragg grating sensors to the tail of the Nishant unmanned aerial vehicle(short for UAV) of the Indian institute of aeronautical development to monitor the strain changes of the UAV. During flight and landing, and assessed the impact of abnormal behaviors on the structural integrity of the UAV during flight.

Civil aircraft are more demanding about safety, so new technology comes late. Fiber Bragg grating sensor research of Boeing and Airbus began in the late 1990s of the 20th century[5]. Testing the structure, chemical corrosion environment of fiber Bragg grating sensor working conditions, and on the Boeing 777 fuselage structure with a fiber Bragg grating sensor for a great deal of experiment, the temperature and stress changes in the latest model of the Boeing 787 fuselage structure equipped with real-time trends to monitor the body structure. Boeing has developed a fiber Bragg grating sensing system to measure the influence of multiple parameters change on the system and test fiber grating sensor structure corrosion chemical environment working conditions. Fiber Bragg grating sensors used to get lots of temperature and stress date on the Boeing 777 body structure and equipped optical fiber nondestructive testing system to monitor the real-time movement of the airframe on the Boeing 787 fuselage structure. LUNA, in collaboration with Boeing and Delta, had experimentally installed fiber Bragg gratings sensors and other humidity, pressure and temperature sensors on a 12-year-old Boeing 767-300er aircraft and got lots of useful data. Airbus, as the leading party in the SMIST (structure monitoring with advanced integrated sensor technologies) project funded by Europe, focused on the study of the airframe health monitoring technology based on fiber Bragg grating sensor, and applied the results to the c-27j transport plane for testing and aerial monitoring. In 1998, German DASA aircraft test center used fiber Bragg grating sensors on the surface of carbon-fiber reinforced composite aircraft wings to monitor the fatigue characteristics of the wings, which is the first achieving composite aircraft structure strain monitoring in Europe. In 2002, the university of Edinburgh installed fiber Bragg grating sensors on the A340-600 fuselage to monitor the temperature and strain of the airframe. In 2007, the university of Madrid attached GLAER curved plate, a composite material of A380 fuselage structure, to four grating fiber optic sensors to study the strain distribution under load and the generation of disbond, delaminate and other defects.

Other countries had also done some research on the health monitoring of civil aircraft by FBG sensors. NEDO and RIMCOF are funded projects for structural health monitoring of composite materials in Japan, and their main direction is to implant fiber Bragg grating sensing technology into the structural health monitoring of aircraft composite materials. In 2004, Japanese scientists designed piezoelectric ceramics and fiber Bragg grating composite sensors, which were applied in small commercial aircraft of all-composite materials to realize the monitoring of composite structural damage. The German aviation center has studied the optical fiber sensing technology on the micro-aircraft aerodynamic load, wing deformation and other key data measurement. Cranfield university has developed an aircraft structure health monitoring system based on speckle interference image at the end of optical fiber, which can be used to monitor the damage status of aircraft carbon fiber composite structures[6].

According to the above research, the application of fiber Bragg grating sensors on aircraft is arranged according to the service time and position, as shown in table 1.

Table1 Development of FBG for monitoring composite structure

Type	Year	Country/Company	Aircraft	Percentage of Composite	Monitoring Position
military	1990's	American military	F/A-18	10%	vertical stabilizer
	1998	American/NASA	X-33	30%	fuselage, fuel tank
	1998	American/Lockheed Martin	X-33	30%	fuselage
	2000's	American military	F-22	24%	fuselage、wings
	2000's	American military	F-35	35%	fuselage、wings
	2001	Germany	X-38	40%	fuselage
	2000's	Indian	Nishant (UAV)	100%	tail
	2010	American/NASA	Predator B (UAV)	100%	wings
civil	1990's	LUNA, Boeing, Delta	B767-300ER	3%	airframe
	1990's	Airbus	C-27J	8%	structural integrity
	2000's	Boeing	B777	11%	fuselage
	2002	Airbus/ university of Edinburgh	A340-600	13%	airframe
	2004	Japan	corporate	100%	fuselage、wings
	2007	Airbus/university of Madrid	A380	22%	GLARE
	2000's	Boeing	B787	50%	fuselage

From table 1 shows that, with an increase amount of composite in aircraft, fiber grating sensors are increasingly applied in the advanced aircraft, such as F-22, F-35, B777, B787, A380, and also expanded to UAV, corporate, micro-vehicle (MAV) and other emerging areas. The monitoring part is also transferred from the non-bearing part of the aircraft to the complex bearing structure. The advanced level in the military field is mainly represented by the us military, while the main achievements of civil aircraft are concentrated in Boeing and Airbus. Other countries such as Japan, Sweden, Germany, India have also carried out relevant research work, with certain research results. Some universities and research institutes in China also have some preliminary studies on the health monitoring of fiber Bragg grating sensors on composite structures, which is far from the advanced level in foreign countries.

4. Conclusion

With the rapid application of aircraft composite materials, there has been a great development in the health monitoring technology of fiber Bragg grating sensors. However, due to the existence of cross-sensitivity, stability, durability, signal demodulation and other problems of the sensor itself need to be solved, It will take some time to apply to aircraft. It can be predicted that in the near future, fiber Bragg grating sensors can play a great role in aircraft state monitoring, structural health alarm, line inspection and so on, and provide more guarantees for aerospace safety.

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