Detection of Damage in Metal Lap Joint by Combined Passive and Active Methods

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Abstract. Fatigue cracks and corrosion damage are critical issues for aircraft, especially for the aging fleet still in use today. The most frequent area of damage is on the aircraft skin, more specifically the joint regions. A structural health monitoring system is being sought after as a system of sensors to detect and localize damage during flight, reducing the amount of time spent in ground inspections and amount of ground inspections overall. Currently, studies from companies and universities are being done, using a variety of different sensing methods, including acoustic emission (AE) testing, ultrasonic testing (UT), and by optical fiber with fiber Bragg gratings (FBG) as strain gages. AE and FBG sensors are passive systems by 'listening' to cracks growth or measuring stiffness change around the crack, respectively. These two methods can be combined to form an active network, checking the other methods in real-time by using guided waves of UT. This study looks at analyzing the abilities of AE and FBG sensors to work as both passive and active systems, comparing results to one another. Due to temperature problems in skewing responses of guided waves, a network of sensors is formed as well to use a correlation in baseline approach, negating this effect, and is tested for fatigue damage on a metal lap joint configuration over cyclic loading. FBG sensors are found to be more directional based and can work in replacing strain gages, while AE sensors can be used well in conjunction with active UT.

1. Introduction

Aircraft, along with all other vehicles, acquire cracks and damage with time and use. In order to prevent failure of parts on vehicles, inspections are made to check for any critical damage. Aircraft have a long lifetime of use and cracks and corrosion might grow around airframe, skin, and other structural components. The current method of aircraft inspection is to take the aircraft apart in a ground inspection and visually locate and determine extent of structural damage or use other ground devices in the inspection. The purpose of this project is to find an *in-situ* structural health monitoring (SHM) system, which can be used to monitor for damage, during flight in real time. This system has the requirements of being automated and using non-destructive evaluation (NDE) to determine damage, without disrupting the function of the structure being monitored. Along with this, the SHM system being sought should be more reliable than the actual structure and have a minimum of components in order to reduce costs and minimize the weight of the aircraft in flight. Though the SHM system can not fully eliminate the need for ground inspection it should reduce significantly the time required thereby reducing the cost of operation of the aircraft.

A major component of aircraft, which accumulates damage, is the thin external skin. Portions of the skin of an aircraft are loaded in tension, and they are subjected to pressure and temperature changes during flight, including all aerodynamic forces. Since the aircraft skin has an average thickness of around 2 – 3mm, damage can easily become a problem. Cracks and corrosion have been discovered to initiate and grow around joint regions, due to metal contact and preexisting holes for rivets to attach multiple layers. The author of this paper is interested in finding a suitable method of monitoring skin joint regions on an aircraft structure.

2. Discussion

The results of an exhaustive literature investigation indicate that current technologies, showing the most promise, are in the ultrasonics field. Ultrasonic Testing can further be broken down into passive (acoustic emissions) and active (Lamb wave) modes.

Acoustic Emission

Acoustic emission (AE) is a form of passively monitoring a structure using piezoelectric sensors. When a crack initiates within the structure and grows larger, elastic and plastic strain waves travel outward through the material. These strain waves, which are in the frequency range of 250kHz to 20MHz, can be "heard" using these AE sensors. These sensors can hear waves emanating from a crack as far as tens of feet from the sensor. Along with hearing the damage, multiple sensors could be used to triangulate or locate the damage. Due to the passive setting of waiting for the damage to make waves of its own, the system would require a low amount of power and has little to no sensor drift. Filters have been created to contain white noise levels; however, only a very basic amount of information can be obtained about the damage[1].

Lamb Waves

Guided waves were first predicted by Lord Rayleigh in the 1880's and later improved upon by Horace Lamb, giving them the name Lamb waves. These waves travel along the surface of a material in the form of strain waves. These are complex, having to be broken down into symmetric and anti-symmetric modes for study, similar to the manner that Fourier series can be used to break down complex signals into even and odd oscillating waves[2]. From the characteristics of Lamb waves, a frequency range around 2MHz is used for this method as only the initial symmetric and asymmetric modes are present. This allows for easier analysis.

For a thin plate structure, piezoelectric actuators and sensors can be attached in a manner to send pulses of Lamb waves through the structure and receive them in the sensors. This helps with damage detection because if any damage occurs, a ripple, or change in the signal, will occur. Using the timing of the ripple, the damage location can be located. Since the skin of the aircraft is a thin-walled structure, these waves can be used to determine any changes in the structure.

The structural responses of many aircraft components are nonlinear, so a baseline measurement is needed as a standard. Each thin-walled component will have a distinct signature frequency, and any damage would alter this in some way. For this active scanning method, a number of solutions have been considered. One, which looks promising, is a statistical correlation method, similar to that employed with the strain gage method, but happening in real time[3]. This can be coupled with the newer technology of fiber Bragg gratings.

Fiber Bragg Gratings

Optical fibers can be used to measure the elongation of the fiber and thus strain within a structure. Fiber optics measure a light wave pattern traveling through each fiber. Any deformation in the fiber will result in a change in wave shape, which can be analyzed by a signal conditioner. This is done through Fiber Bragg Gratings (FBG). These are diffraction gratings, made within the optical fiber. A Bragg wave is generated by the light source and travels through the optical fiber. As it comes to the FBG, a small portion of the wave is reflected back. The wavelength of the reflection is determined by the elongation or strain applied to the FBG. Therefore it acts as a strain gage, and is being researched as replacing current strain gages on aircraft to monitor in-flight conditions.

In addition to acting as a strain gage, fiber optics can have a high sampling rate, which can then in turn act as a passive receiver of Lamb wave pulses from ultrasonic, piezoelectric components [4].

3. Conclusion

The ideal system for aircraft SHM on the skin should not be just one of the methods discussed above, but rather an integrated combination. A passive/active system seems to be the top choice for this problem. Acoustic Emission (AE) sensors and fiber optics with FBG's could be used as a passive system, continuously monitoring the structure for the onset of damage and current in-flight conditions. Their low power and ability to monitor for general damage would be useful. The system could also be operated in active mode at set periods of time to check results from the passive system, since the active gives better results at the price of more power. Once damage is found, the SHM system would then switch to an active monitoring mode, using actuators to use UT in the damaged area. With piezoelectric materials, the AE sensors could switch to an active ultrasonic mode in the local area of identified damage, minimizing the amount of sensors needed. Also the actuators themselves could be separate, or derived from the AE sensors. Along with the AE sensors, the nearby FBG's could read any ultrasonic pulses and be used as well to search for damage. This results in a health monitoring system, consisting on a minimum amount of sensors, which is able to cover a large area and scan for damage.

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