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Detection of cuts and impact damage at the aircraft wing slat by using Lamb wave method

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ABSTRACT

Lamb wave based techniques have been widely used for structural health monitoring (SHM) applications. Most of the studies used either plates or built simple structures similar to airplane fuselage. In this study, the actual wing slats of Boeing 737 aircraft was used for detection of typical damages observed at the normal operating conditions. The cuts and impact damages of the slats were considered. The trailing edge of the slat was made of Al 2024 with 1 mm thickness. This section was supported with a composite honeycomb core. The material of the front section of the slat was Al 7075 with 2.5 mm thickness. Four lead zirconate titanate (PZT) discs were attached to the sections of slats to create surface waves and to monitor their propagation. The envelopes of the monitored signals were calculated by using the Hilbert transform. The cuts generated new boundaries and created well defined reflected waves which may be used to estimate the location of the defects from their arrival time. The impact damage could be detected from the change of the pattern but interpretation of the signal and estimation of the location was much more complicated. The study indicated that the defects of over 3 m long slats can be detected with carefully located PZT discs.

1. Introduction

Structural health monitoring (SHM) [1] techniques were developed to evaluate structural integrity without using the labor intensive nondestructive evaluation (NDE) methods including eddy current probes, ultrasound, magnetic particle testing, X-rays, thermography, and visual inspection [2].

Liquid penetrant testing is used to inspect large areas very efficiently and it works on many nonporous materials. Main advantages of this technique; large surface areas can be check rapidly and at low cost. Minimum equipment is needed for inspection. However, penetrant testing detects only surface breaking defects. It requires a smooth, non-porous surface, post cleaning to remove chemicals and multiple operations.

Magnetic particle testing can be used for only ferromagnetic materials. It detects surface and near-surface defects for large and complex parts. But large currents are needed for large areas. Beside this, paint or other nonmagnetic covering affects sensitivity and demagnetization is usually necessary.

Eddy current method used to detect surface and near-surface flaws in conductive materials. In this technique the test probe does not need to touch the surface. But it has disadvantages like limited areas, extra scan time, limited penetration and it needs more extensive skill and training than other techniques.

X-rays are used to produce images of objects using film or detector. It is used inspects many material for surface and subsurface defects and it has ability to inspect complex shapes and multi-layer structures. The disadvantages of this technique are extensive operator training, expensive equipments, extra time and possible radiation hazard for personnel.

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Ultrasonic method is used to locate surface and subsurface defects in many materials including metals, wood, plastic and composite. This technique is better in depth penetration for defect detection against other techniques. It also provides distance information but it needs more extensive skill and training. The other disadvantage is difficulty in detection thin structure.

Lamb wave, which kind of a sound wave, are the most commonly used plate waves in NDE. If a large structure is to be tested, the transducer must be scanned over the whole surface in conventional ultrasonic test. This process can be very time consuming. But Lamb waves can travel several meters in metals and so are useful to scan plate, wire, tube or long structures. Unlike other ultrasonic techniques, thin structures can be easily inspected by the Lamb wave. To generate Lamb wave, very cheap piezoelectric transducers can be use. Unfortunately, Lamb wave testing is complicated by the dispersive nature of Lamb waves and it needs data acquisition and signal processing equipment or software [3–5].

NDE methods have been used as part of the schedule based maintenance. SHM methods allowed the implementation of condition based maintenance. Condition based maintenance methods predict the future defects with the help of sensors and eliminate the unnecessary service and part replacement of conservative schedule based maintenance. In addition, the SHM systems may be used during the flight for detection of developing defects and avoid accidents. In this paper, detectability of the cuts and impact damage at more than 3 m long slats of the wings of Boeing 737 aircraft were experimentally studied.

During the operation of aerospace vehicles, fatigue and impacts of low velocity objects create damages. These damages may grow to a critical size and create catastrophic accidents. Some of the current commercial SHM systems are capable to detect structural defects. Once, the SHM systems detect the problems more sensitive NDE techniques may be used to determine the extent and exact location of the damage [6]. SHM community has been working on improving their methods to provide extensive information about the location, nature, and severity of the damage [7,8] without requiring additional NDE work. Such systems are hoped to follow the growth of the damage and require replacement of the defective parts just before the damage reach to the critical size [9].

SHM methods may use passive and active systems. All the SHM methods use computer hardware for control of the system and process of the data. Passive systems monitor the characteristics of the structure by using sensors while the active systems excite the structure and monitor the response. Active systems use one or more actuators to excite the structure to generate surface waves. The piezoelectric elements are the most widely used exciters for the SHM systems. For measurement of physical characteristics both systems use sensors such as acoustic sensors

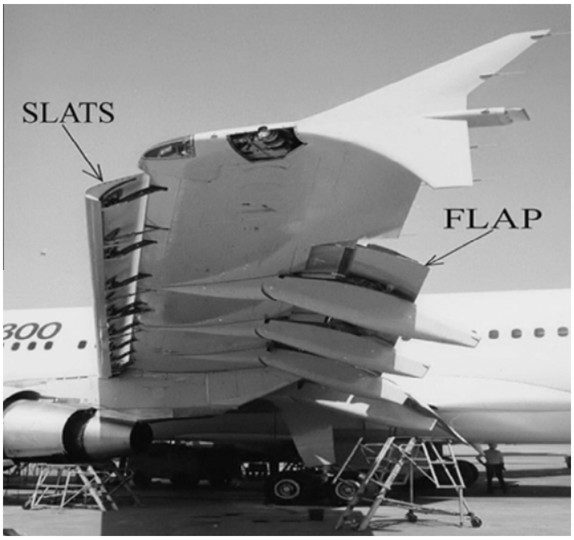

Fig. 2. Slats position on an aircraft.

[10], piezoelectric materials [11–13], optical fibers [14–16], laser vibrometer [17], accelerometers [18] and structure-embedded sensors [19–21]. Many researchers have worked on development of SHM methods by considering plates and fuselage of the aerospace structures in the past. Implementation of these methods in the industry by considering the future needs have recently started [22]. A rich SHM literature is available for selection of the most convenient sensors and computational method for various applications [23–35].

PZT and other piezoelectric materials change their dimensions when they are subjected to charge and vice versa. SHM community used them for creation of surface waves and monitoring of the propagation of them [28,36]. The guided waves, Lamb waves can be created by applying small voltages to relatively cheap piezoelectric materials. Even large thin plates may be inspected with the Lamb waves since they travel long distances without any significant amplitude loss [37]. Researchers have used the Lamb wave approach for detection of cracks in aluminum plates, delamination in composite plates, and corrosion in pipes [38,39]. Time and cost savings [40], and improvement of the safety of the aircraft has convinced two recent major aircraft programs (Boeing 747 and Airbus A380) to consider using the SHM systems at the critical areas for detection of impacts and evaluation of the structural integrity [27,41].

The sensory signals in the SHM applications have complex waveforms and process of the signal is necessary for visualization of their characteristics. The energy or the amplitude of the signal could be calculated by using the Hilbert transformation. It is possible to visualize the

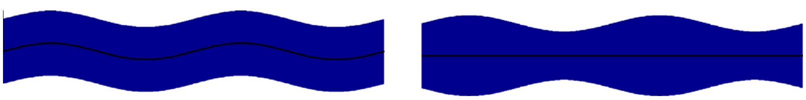

Fig. 1. Representation of Lamb wave modes: (left) anti-symmetric mode and (right) symmetric mode.