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The Acousto Ultrasonic Structural health monitoring Array Module (AUSAM$^+$) for Damage Detection in Structures

Joel Smithard[a], Patrick Norman[a], Steve van der Velden[a], Ian Powlesland[b], George Jung[a], Nik Rajic[a]* and Steve Galea[a]

[a] *Aerospace Division, Defence Science and Technology Group, 506 Lorimer St., Fishermans Bend, VIC 3207, Australia*
[b] *Formally DST Group (Retired)*

Abstract

An area of considerable interest within the aerospace community is the use of structurally-integrated transducers for detecting and monitoring damage in aircraft structures. Such Structural Health Monitoring (SHM) systems offer the possibility to provide non-destructive inspections on-demand and consequently provide a basis for condition-based maintenance on airframes. This approach potentially offers maintenance cost savings and possible improvements in performance when compared to current time-based techniques for detecting and monitoring structural damage. A wide-area damage detection technique under extensive investigation by researchers, on small-scale coupons to full-scale test articles, is acousto-ultrasonics (AU) using structurally-integrated piezoelectric transducers. For any SHM technique to be successfully applied to an operational aircraft in the field the SHM hardware needs to be fit for purpose i.e. easy to use, compact, portable, light, electrically and mechanically robust and provide reliable and accurate measurements. Additionally, in order for researchers to extend, demonstrate and validate AU based SHM techniques under various aerospace structural scenarios, instrumentation is required that is functionally flexible, expandable and relatively inexpensive. In order to facilitate the development, validation and implementation of AU based SHM in the aerospace community the Australian Defence Science and Technology Group (DST Group) has developed a compact device for AU excitation and interrogation, called the Acousto Ultrasonic Structural health monitoring Array Module (AUSAM$^+$). The module, which has the footprint of a typical current generation smart phone, provides autonomous control of four send and receive piezoelectric elements, which can operate in pitch-catch or pulse-echo modes and can undertake electro-mechanical impedance measurements for transducer and structural diagnostics. Other key features include an ability to (1) accommodate larger transducer arrays by operating synchronously with other units, via an optical link; (2) cater for fibre optic sensing of acoustic waves with four intensity-based optical inputs; (3) measure temperature and strain; (4) be triggered externally; and (5) allow the users to easily access the full hardware functionality via a Matlab or Python hardware object, thus

* Corresponding author. Tel.: +613-9626-7193
E-mail address: Nik.Rajic@dsto.defence.gov.au

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providing enormous flexibility for the creation of custom interfaces. This paper provides an overview of the system and its capabilities and demonstrates the efficacy of the system via a simple laboratory AU study on a flat plate.

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1. Introduction

Incorporating transducers permanently within aircraft structures potentially enables on-demand non-destructive inspection (NDI) and could provide a basis for the development of condition-based maintenance approaches for airframes. These structural health monitoring (SHM) systems consequently offer the potential for sustainment cost savings, increased aircraft availability, the introduction of agile automated logistical approaches as well as performance improvements over conventional NDI as well performance improvements over conventional NDI as well as an increase in aircraft availability. Currently, a promising wide-area diagnostic tool under extensive investigation is acousto-ultrasonics (AU) [1,2,3]. The approach typically involves the attachment of a low density array of piezoelectric elements to provide the necessary Lamb waves excitation and sensing functions for AU interrogation in either pitch-catch or pulse-echo modes. Fibre Bragg gratings (FBG) offer an alternative sensing system for AU applications in the pitch-catch arrangement [4]. The introduction of FBGs as a sensing tool offers the ability to provide temporal and spatial elastic wave measurements using an array of distributed FBGs in the one fibre [5].

From an aircraft maintenance perspective AU-based SHM may be applied either in the hanger during regular or ad-hoc maintenance actions or during flight. For either approach the hardware for the AU interrogation needs to be fit for purpose, i.e. easy to use, compact, portable, light, electrically and mechanically robust and provide reliable and accurate measurements. If the instrumentation is to be installed on the aircraft then it must also be fit for flight, i.e. flight certified. From a research perspective the instrumentation should be highly flexible in its operational configuration in order to investigate the numerous scientific and engineering issues associated with AU based SHM.

With the above drivers in mind, the Defence Science and Technology (DST) Group has developed a light robust and compact portable device, called the Acousto Ultrasonic Structural health monitoring Array Module ($AUSAM^+$), for high bandwidth (up to 5 MHz) AU excitation and interrogation. The $AUSAM^+$, which is a substantial upgrade from the original AUSAM [6], has the footprint of a typical smart phone, provides autonomous control of four send and receive piezoelectric elements, can operate in pitch-catch or pulse-echo modes and can undertake electro-mechanical impedance measurements for transducer and structural diagnostics. The module also caters for optical fibre sensing of acoustic waves with four intensity-based optical inputs and allows the users to easily access the full hardware functionality via a Matlab or Python hardware object. This paper provides an overview of the system and its capabilities, and demonstrates the efficacy of the system via a simple laboratory AU study on a flat plate.

2. System Overview

2.1. Overview

The AU-SHM activities within DST Group have focused on using high order Lamb waves to bolster the diagnostic information during AU interrogation rather then using conventional approaches which mainly focus on interrogation below the first cut-off frequency. In order to excite these higher order modes, high excitation voltage (over 100 Vp-p) with high frequency response (up to and exceeding 2 MHz) is required. With the absence of COTS instrumentation to achieve such demands with adequate noise performance, reliability and device size, DST Group initiated a program to design instrumentation capable of driving a piezo-ceramic transducer with capacitance ranging from 1 nF to 10 nF at excitation voltages of 200 Vp-p over a frequency bandwidth of 50 kHz to 5 MHz. A