HEALTH MONITORING OF WING STRUCTURE BASED ON BUILT-IN TRANSDUCERS AND A PULSE LASER

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1 Introduction

As scores of built-in diagnostics were developed for individual structural hot spots of the aircraft structure, the disbond monitoring at the stringer tip has been also approached with built-in ultrasonic transmitters and receivers [1-3]. In case of the wingbox with stringers, debonding is substantially initiated at the stringer tip owing to the fatigue loading related to the aerodynamic lift and weight forces. Therefore, the related industries require development of a built-in structural health monitoring (SHM) technology for that part. For this work, we propose a method capable of more quantitative correlation between the ultrasound and the disbond growth at the tip of a wingbox stringer where the information on both arrival time and amplitude is utilized.

An ultrasonic transmitter permanently built-in a structure can be combined with external ultrasonic receivers such as air-coupled transducer and laser vibrometer for an advanced NDE [4-5]. Here we propose a reciprocal setup, i.e. built-in ultrasonic sensor/laser ultrasonic generator. For a pulsed laser as an external ultrasonic generator, we can expect the merits such as curved surface scanning, larger scanning area and faster scanning time due to no requirement in focal length.

2 Built-in diagnostics using small-size transducers

2.1 Disbond monitoring principle at stringer tip

To develop a diagnostics for disbond monitoring, the current study first uses an Al-alloy model of the skin-stringer structure. The specimen consists of a bonded angle stringer and skin assembly as shown in Fig. 1. The principle of the disbond growth monitoring for this work is explained in Fig. 2. In case without disbond as shown in Fig. 2a, the receiver installed on the flange edge directly detects the ultrasonic wave sent by the transmitter installed on the skin. However, in case with a disbond as illustrated in Fig. 2b, the wave sent by the transmitter should travel a longer distance in the skin and turn back along the new path in the flange caused from debonding in order to arrive at the center of the receiver, i.e. sensing point.

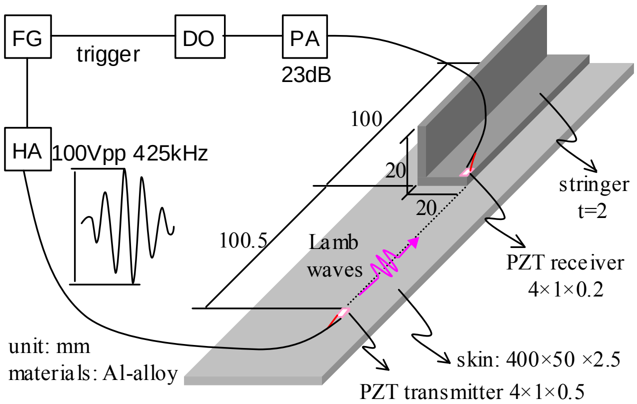

Fig. 1. Experimental model and ultrasonic setup.

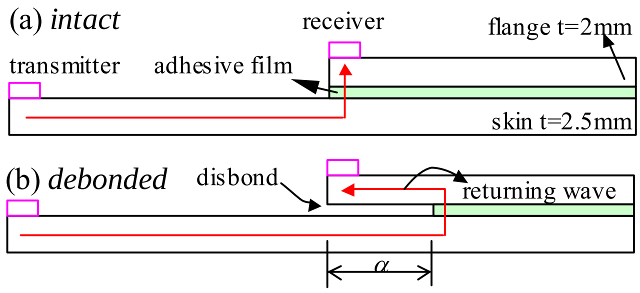

Fig. 2. Disbond monitoring principle.

Given that the receiver is a point-wise sensor, the ultrasonic path difference before and after debonding are $2\alpha_{s}$, α in the skin and α_{s} in the flange where α_{s} is the disbond length parallel to the ultrasonic path. Therefore, the arrival time (τ) can be calculated as follows:

$$\tau = (1/c_{sk} + 1/c_{fl})(\alpha - \alpha_s) + \tau_0 \qquad (1)$$

where α_s is a distance between the flange tip and the sensor, c_{sk} is a wave velocity in the skin, c_{fl} is a wave velocity in the flange of the wave returning from the disbond termination and τ_0 is an arrival time in case without disbond. Therefore, we can make a linear correlation between the disbond length and the measured arrival time using Eq. (1).

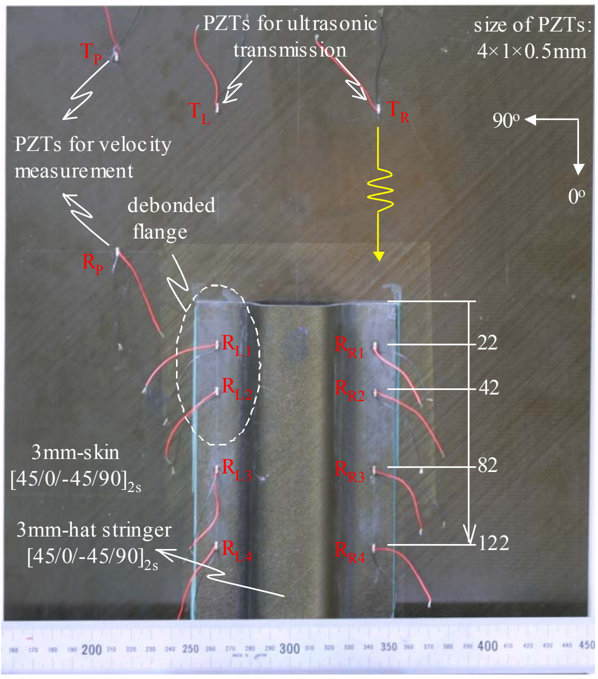

Fig. 3. PZTs for CFRP skin-stringer structure.

2.2 Diagnostics verification in metal skin-stringer

As presented in Fig. 1, two PZT transducers with in-plane dimensions of 4×1 mm^2 are bonded in the flange corner and in the skin, respectively. Ultrasonic pitch-catch is carried out with respect to the increase in size of an artificial disbond. The arrival time and amplitude curves are reported and the diagnostics based on the arrival time delay is verified with Eq. (1).

2.3 Application to composite skin-stringer

The returning wave-sensing method illustrated in Fig. 2 is next applied for a real skin-stringer structure for a CFRP wingbox. The structure (Fuji Heavy Industries Ltd.) consists of a hat stringer and skin assembly as shown in Fig. 3. The disbond length is quantitatively evaluated by the built-in diagnostics and then compared with ultrasonic C-scan result.

3 Advanced NDE based on laser ultrasonic generator/built-in sensor reception

Since the structure has already ultrasonic transducers under the built-in SHM scheme, either actuator or receiver is needed for the realization of an advanced NDE. Since the ultrasonic wavefield imaging technology [5] is based on a scanned 2-D or moving image, it allows for easy understanding about wave propagation mechanism and clear interpretation about structural damage. For this approach, we utilize a pulse laser as a scanning ultrasonic generator and a built-in sensor as an ultrasonic receiver. Fig. 4 shows a result of the disbond detection near the stringer tip. The other results obtained by the built-in sensor and laser ultrasonic scanning will be presented in the form of the wave propagation movies.

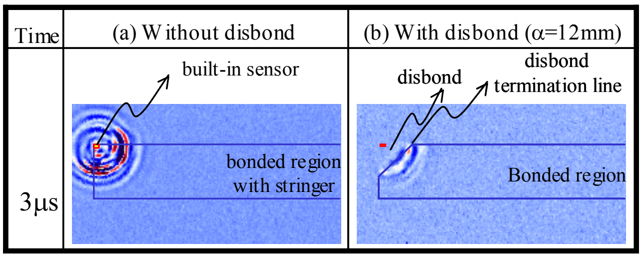

Fig. 4. Wavefields before and after debonding.

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