Defect visualization of aircraft UHF antenna radome using full-field pulse-echo ultrasonic propagation imaging system

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Abstract. Most of aircraft antennas usually have various types of radome made of composite materials for protecting antenna structures. However, these antenna radome structures, which are installed on the outside of airplane, are easy to be damaged by external forces such as drag, foreign object, bird strike and others. In this study, full-field pulse-echo ultrasonic propagation imaging (PE UPI) system is proposed as the non-destructive inspection technique to visualize manufacturing defects in composite antenna radome. Based on the results of the sample case study, it is shown that the ultrasonic wave propagation imaging (UWPI) that is generated by the proposed full-field PE UPI system is able to highlight the intact internal condition of antenna structure and its defect area. Additional damage visualization techniques like ultrasonic energy mapping (UEM), variable time window amplitude map (VTWAM) and also ultrasonic spectral imaging (USI) algorithms are applied to improve the reliability of the damage visualization. It can be concluded that the proposed PE UPI system is an effective non-destructive inspection technique for the composite radome structures.

1. Introduction
Antennas for radar, communication and other wireless devices are commonly equipped on airplanes. These antennas usually have various types of radome made of composite materials for protecting them. Most of the radome structures are installed on the outside of airplane that makes it easy to be damaged by external forces such as drag, foreign object, bird strike and others. If the radome structures have internal defects induced by their manufacturing process like voids, porosity, fibre disorientation and resin rich or resin starved areas, these internal defects can give cause of damage in combination with the external impact, fatigue or load [1].

Manufacturing defects of radome structures generally can be detected by non-destructive inspection technique such as visual inspection, ultrasonic testing, radiography and others. Visual inspection is applied basically because of ease of inspection by the naked eyes with simple optical device despite its difficulty to find internal defects [2, 3]. Meanwhile, radiography is the most common non-destructive testing method to inspect the internal structure by x-rays or gamma rays [4]. However, this method has...
limitations due to the hazardous radiation exposure that can affect the health of the inspectors. On the other hand, ultrasonic testing method is the most effective technique to inspect composite structures. The pulse-echo technique, which is one of ultrasonic testing methods, has been widely used for aircraft structures inspection [4]. However, the typical ultrasonic testing method still has some weak points in need of improvement such as spreading coupling agents on the surface and inspecting curved surface.

In this research, full-field pulse-echo ultrasonic propagation imaging (PE UPI) system with various post-processing damage visualization technique has been applied to detect the manufacturing defects of composite antenna radome structure.

2. Full-field pulse-echo ultrasonic propagation imaging system
Figure 1 shows a concept of full-field PE UPI system that has been configured for ultra high frequency (UHF) antenna radome inspection. The full-field PE UPI system is consisted of a 1064 nm Q-switched laser, 2-axis translation stage, a 633 nm laser Doppler vibrometer (LDV), a PC and also a band-pass filter.

In a general UPI system, the scanning laser beam generates ultrasonic waves on the target surface and a fixed ultrasonic sensor acquires the propagated ultrasonic waves along the surface of the target [5]. On contrary, the proposed full-field pulse-echo UPI system is operating with different mechanism based on pulse-echo technique shown in Figure 2. Laser beams of the Q-switched laser and LDV are impinged along raster scanning pattern on the target surface by two-axis linear translation stage. The laser beam impinged by Q-switched laser generates ultrasonic waves from thermoelastic effect on the surface of target. These ultrasonic waves propagated through the thickness direction and are reflected by the internal structures and opposite surface [6]. The reflected ultrasonic wave signals are acquired by LDV and then processed in the PC. Finally, ultrasonic wave propagation imaging (UWPI) movie is generated along with several post image processing result.

Figure 1. Concept of full-field pulse-echo UPI system
In this research, ultrasonic energy mapping (UEM), ultrasonic spectral imaging (USI) and variable time window amplitude map (VTWAM), which are post image processing algorithms for previously developed UPI system, are applied to the PE UPI system for the first time. The UEM technique is a damage visualization algorithm to visualize energy of scattering waves filtered as a single wave mode (S0/A0/S1/A1, etc.) based on wave number filtering [7]. On the other hand, the USI technique is one of damage visualization algorithms to visualize damages by mapping the time domain signal that has been transformed to frequency domain using fast Fourier transform (FFT) [8]. Last but not least, the VTWAM algorithm is able to visualize the damages by mapping the averaged signal values in chosen specific time range from the UWPI data [9].

3. Defect visualization of GFRP UHF antenna radome structure

The damage visualization experiment was performed using the full-field PE UPI system to visualize internal defects of a glass fibre reinforced plastic (GFRP) antenna radome structure. As illustrated in Figure 3, the size of radome is 359.5 mm ×320.6 mm ×116.67 mm. The shape of the antenna is blade-type structure like a dorsal pin. Scan area 1 was 312 mm ×130 mm while scan area 2 was 312 mm × 52 mm, both with the same interval of 0.52 mm. The stand-off distance was 1.5 m from the full-field pulse-echo UPI system to the target surface. The energy of Q-switched laser was 3.5 mJ and the pulse repetition frequency was set to 1 kHz. The signal acquired was also filtered using band-pass frequency between 20 – 200 kHz.

The generated UWPI results are shown in Figure 4. No defect is visualized in Area 1 except for a peeling paint area of skin. Meanwhile, a defect of size of 40 mm × 2 mm was detected in the UWPI result of Area 2. Damage visualization techniques: UEM, VTWAM and USI were additionally applied to improve the reliability of damage visualization results as shown in Figure 5. As a result, the damage visualization results of Area 2 show damaged area of size of 40 mm clearly. The defect is estimated as resin-rich area formed along fibre direction of fabric. All in all, it is demonstrated that the developed full-field PE UPI system can provide damage visualization results that show defect area of the antenna structure. These results assured that the full-field PE UPI system is effective in visualizing the defect of the composite structures.
Figure 3. 3D modelling of GFRP UHF antenna specimen

Figure 4. UWPI results (a) Area 1, (b) Area 2
Figure 5. Damage visualization results of Area 2, (a) UEM result, (b) VTWAM result, (c) USI result

4. Conclusion
In this research, a full-field PE UPI system was proposed for actual GFRP antenna radome structure inspection. UWPI result of Area 1 that was generated by the proposed full-field PE UPI system shows an intact internal condition of the antenna structure except for a peeling paint area of skin. On the other hand, UWPI result of Area 2 shows defect area. Additional damage visualization technique such as VTWAM, UEM and USI were also applied to improve reliability of damage visualization results. As a result, the visualizations show clearly the damaged area that is believed to be a resin-rich area formed along the fibre direction of fabric. The results assured that the full-field PE UPI system is effective in visualizing defect of composite structures.

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