Impact damage detection using broadband ultrasonic guided waves for health monitoring of CFRP mobility structures

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Nowadays, carbon fiber reinforced plastic (CFRP) laminates have been used as the structural components of personal mobility in order to reduce its weight. However, the personal mobilities are more likely to suffer from barely visible impact damages (BVIDs) while owner is not aware. The BVIDs may cause a significant degradation in the performance, seriously affecting the safety of daily use. Hence, structural health monitoring (SHM) systems that can detect the BVIDs in mobilities are urgently needed. In this research, we attempted to establish a method to evaluate impact damages in mobility structures made of CFRP based on ultrasonic guided waves. Experiment was conducted to investigate the relation between the impact damage size and the time of flight (ToF) delay of travelling A0 mode. Since the ToF delay of travelling A0 mode may vary depending on the frequency, a broadband chirp signal was input to a transducer. Then, from the signal received by other transducer, we calculated the response signals of tone bursts at desired frequencies using a transfer function method. Extracting the maximum ToF delay over a broad bandwidth, we found that the maximum ToF delay increased linearly with an increase in the damage size. By modeling the impact damage as a cylinder area with a uniform stiffness degradation, same phenomena were observed in finite element (FE) simulations. Hence, ToF delay of travelling A0 mode can be used to quantitatively evaluate the size of the impact damage in CFRP structures. Additionally, analytical calculation based on Mindlin plate theory were conducted to investigate the scattering of A0 mode at impact damaged area, because it is possible to detect BVIDs effectively in a large area using the scattering waves. The speed of the analytical calculation was much faster than that of FE simulation, helping us to investigate the scattering waves quickly in different cases of interest. It was found that the angular distribution of ToF delay of scattered A0 mode over a broad bandwidth was consistent between analytical results and experiment results. Hence, when ToF delay is experimentally obtained for the A0 mode scattered in a certain direction, we can calculate the ToF delay in 0° direction (the incident direction) using the analytical results of the angular distribution. This helps to better evaluate the impact damage size in a large area. In summary, this SHM method using chirp ultrasonic waves is able to quantitatively evaluate the size of the impact damage in a large area in mobility structures made of CFRP laminates.