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Fatigue damage monitoring of an airplane wing using active-sensors

* Jun Young Jeon[1)] Hwee kwon Jung[2)] and Gyuhae Park[3)]

[1), 2), 3)] *School of Mechanical Engineering, Chonnam National University,*
Gwangju, Korea
[3)] *gpark@chonnam.ac.kr*

ABSTRACT

This paper presents the results of fatigue damage monitoring of an airplane wing using guided wave based active-sensing techniques. Aerospace structures experience fatigue loadings under extreme environments during high-altitude operation, which causes structural damage such as fatigue cracks and delamination. For this study, in order to simulate extreme environment of real flight conditions, a specifically designed environment chamber was built and three cases of harmonic fatigue loadings were randomly provided to an airplane wing. Piezoelectric transducers were installed to the upper and lower side of the structure to generate and sense guided wave data. The collected data were processed using spatial filtering to localize and monitor fatigue damage growth. Even with significant variation of environments, test results indicate that fatigue damage monitoring utilizing guided waves is possible. In addition, it was found that the sensor validation process under such environments is critical to ensure the success of monitoring. In this paper, hardware and software components of the experiments are summarized and results are presented for validation of the fatigue damage monitoring.

INTRODUCTION

Extensive research efforts have focused on detecting and locating structural damage [1-5]. In this study, we carried out fatigue damage monitoring of an aircraft wing structure under extreme environments. A specifically designed environment chamber was built and three cases of harmonic fatigue loadings (bending, torsion, bending and torsion) were randomly provided to an airplane wing. Piezoelectric transducers were installed to the upper and lower side of the structure to generate and sense guided wave data. The collected data were processed using spatial filtering to localize and monitor fatigue damage growth. To enhance the reliability of fatigue monitoring results, we implemented the admittance-based sensor diagnostic process [6]. This paper summarizes the experimental procedure, signal processing, and results of this investigation.

Experimental procedure

[1)] Graduate Research Assistant
[2)] Graduate Research Assistant
[3)] Professor

Active sensing techniques based on guided waves in the frequency range of 20 to 80 kHz were used for fatigue damage monitoring. Baseline and test data were compared to extract residual signals which contains scattering and reflected waves caused by damage. These residual signals were used to monitor damage initiation and growth. In this study, two baseline concepts were applied..The traditional baseline concept uses difference between baseline and test data set for damage monitoring. The dynamics baseline concept uses difference between each test data set. The dynamic baseline concept allows to monitor damage growth of each measurement interval. These concepts were applied to phase arrayed piezoelectric transducers to detect fatigue damage and growth.

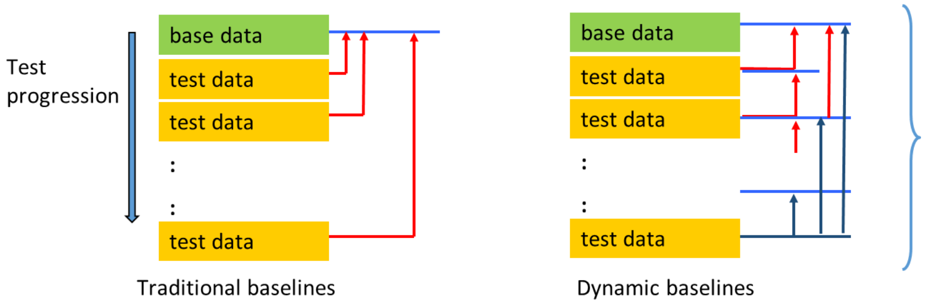

Fig. 1 Traditional & Dynamic baseline concept

The admittance based sensor diagnosis process developed by Park et al. [3] was used to assess sensor status. This method monitors the variation of admittance, which is directly related to the sensors' operational status.

$$Y(\omega)=i\omega\frac{wl}{t_c}\left(\varepsilon_{33}^{T}(1-i\delta)-d_{31}^{2}Y_{p}^{E}+\frac{Z_a(\omega)}{Z_a(\omega)+Z_s(\omega)}d_{31}^{2}\hat{Y}^{E}\left(\frac{\tan kl}{kl}\right)\right) \quad (1)$$

Equation (1) is a function composed of geometric and material properties of a PZT patch. If any geometric constants or electrical and mechanical properties changes, the slope of admittance will be modified, especially in the imaginary part. The results also showed that there will be a meaningful admittance change if there is a de-bonding between a sensor and a host structure. Therefore, damage on the sensor including both fractures and de-bonding could be identified by monitoring the slope of electrical admittance.

EXPERMIENTAL SETUP

A cooling chamber was designed for extremely low temperature environments. The test structure is 4-m long with geometry similar to a wing, which consists of composite plates and inner spars. Before the fatigue monitoring test, initial delamination was introduced at three different locations on both upper and lower sides of the structure. Fatigue loadings were provided to this structure inside the chamber using a hydraulic actuator. Three different types of harmonic loadings were provided.

In order to measure the dynamic response of the structure, piezoelectric sensors are installed on the upper and lower side of the airplane wing. All the sensors are covered by Stycast epoxy to protect them against the low temperature.

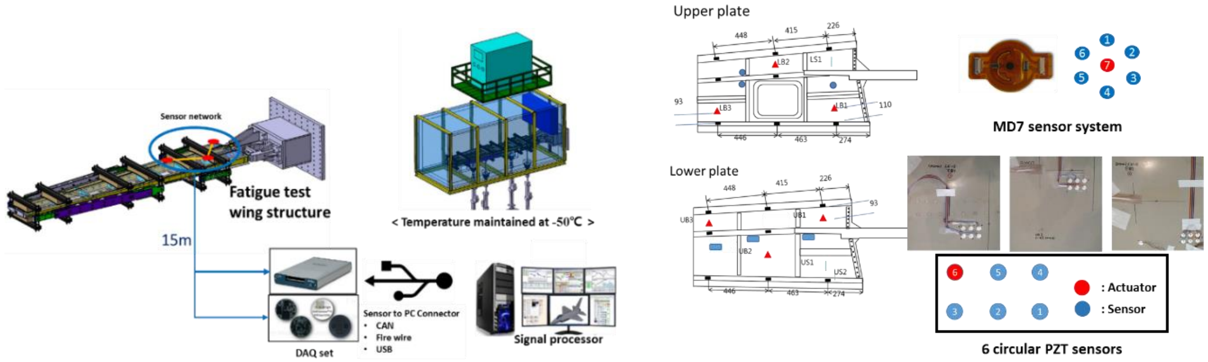

Fig. 2 (a) Test set up (b) Sensor installation

Experiment Result

Before the fatigue test begins, simulated damages were introduced by attaching a piece of metal with 1cm of diameter. Results showed that it was possible to detect and localize damage accurately with the guided wave data. When additional metal pieces were attached, the responses show larger variations, which confirms that active sensors could be used to fatigue damage detection and monitoring for this structure.

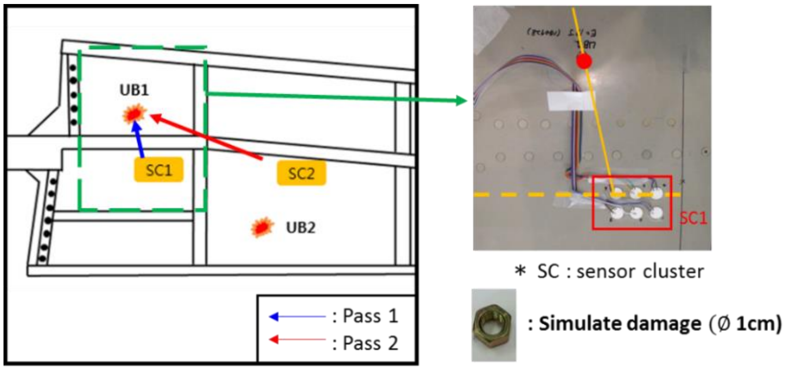

Fig. 3 Simulated damage

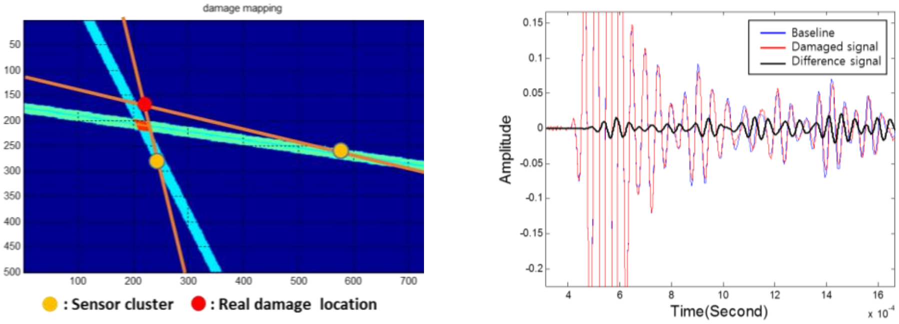

Fig. 4 (a) Damage detection Result (b) Signal difference

Figure. 5 shows admittance slope of the installed sensors at initial state. The slopes of each sensor are almost the same with the maximum variation of the slopes within 2%. When sensors are in extremely low temperature, the slopes are decreased by 20%. However, the relative difference between the sensors remain the same in both room and extreme temperatures

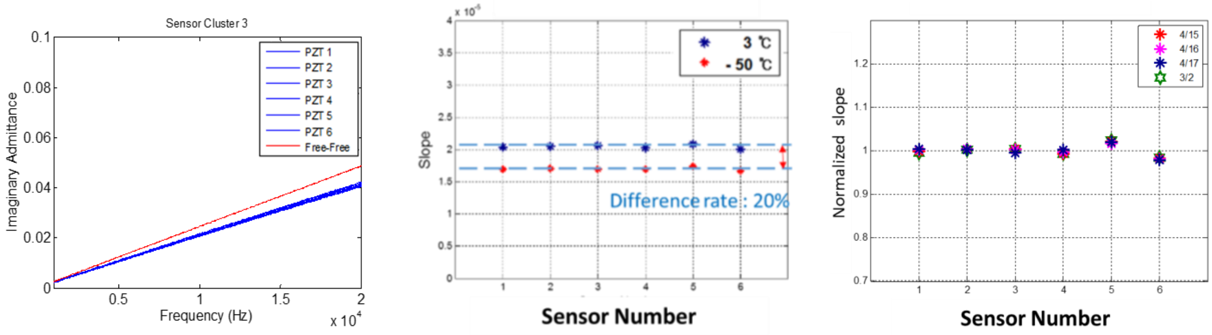

Fig. 5 (a) Admittance slope at full bonding state (b) (c) Admittance slope change of the same sensor array in temperature and time variant

After 300, 000 cycle loadings, the piezoelectric sensors did not show any meaningful damage indication. An NDE inspection was performed to assess state of the structure, and found no fatigue damage initiation, which confirms the active-sensing results. As shown in the figure, there are very small variations of the measurements during the test.

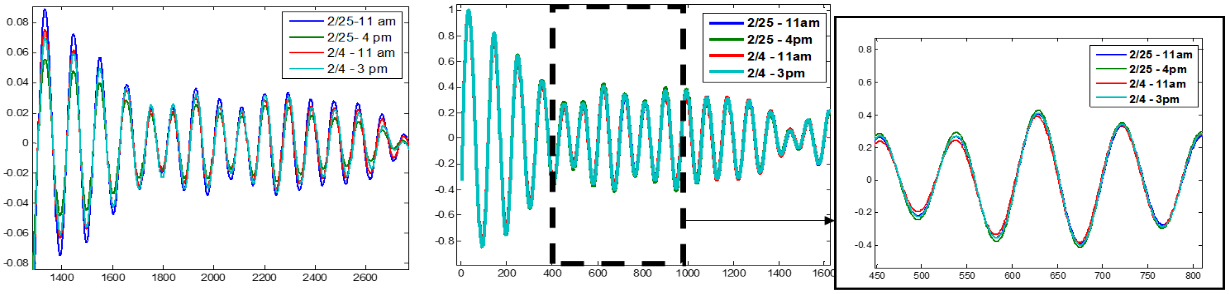

Fig 6. (a) Baseline signal under Extreme environment, (b) Normalized base signal

CONCLUSION

In this study, the unique fatigue test was conducted at the temperature similar to the high altitude flight. During the test, the guided wave based active sensing technique was used to detect and monitor fatigue damage on the wing structure. In order to enhance the reliability of the monitoring results, a sensor diagnostic procedure was also implemented. With the active-sensing techniques, simulated damage were accurately detected and localized. With the sensor diagnostics procedure, the operational status of the sensors were successfully monitored during the test. At the 300,000 loading cycles, there is no damage indication in the structure, which is confirmed by the active-sensing systems and an NDE approach. The test is planned to be continued until an ultimate failure occurs.

ACKNOWLEDGMENTS

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