Damage detection in composite skin stiffener with hybrid PZT-FO SHM system

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**Keywords:** damage detection, lamb wave, structural health monitoring, PZT actuator, Fibre Optic sensor, composites

**Abstract.** A hybrid piezoelectric (PZT)/fibre optic diagnostic system has been developed for damage detection in built up composite structures. The hybrid system uses PZT transducers to actuate the structure and fibre optic (FO) sensors to capture the propagating wave. The diagnostic system will then have the advantages of both PZT and FO sensors. The applicability of the system is then tested for detecting an artificial damage at a skin/stiffener interface of a thick composite structure. The response of the FO sensors is then compared to PZT sensors and presented.

**Introduction**

Structural Health Monitoring (SHM) technology is a relatively new concept which has emerged with advances in sensor technology and signal processing. It can significantly improve the safety and reliability of maintenance of in-service structures while providing lower inspection costs and downtime. The concept of SHM is based on continuously monitoring the response of the structure in service with permanently installed sensors and real-time data processing.

Based on the type of sensing and actuating technology, SHM systems can be divided into Passive and Active systems. Passive SHM systems use only sensors to mainly provide impact detection and characterization [1, 2]. By characterizing the impact energy or contact force, the engineer will have an insight into whether the impact could have resulted in Barely Visible Impact Damage (BVID) or it was not alarming and hence no maintenance action is required. In active sensing, actuators are used to excite the structure and sensors to record the response which can provide information on detection, localization and identification [3-6]. Different transducer technologies can be used for both active and passive system. Piezoelectric (PZT) transducers are one of the most used technologies in SHM due to several advantages such as light weight, low energy requirements for excitation and their electro-mechanical coupling which makes them applicable as both actuators and sensors. They can be used for exciting and sensing ultrasonic guided waves or the electro-mechanical response of the structure [7].

In a hybrid system the advantages of utilising PZTs as actuator is combined together with the advantages of the FO sensors which are high sensitivity to strain, low weight, temperature compensation, possibility of multiplexing and immunity from electromagnetic interference. Multiple Fibre Bragg Grating (FBG) sensors can be engineered on a single fibre. Each FBG is written at a different wavelength, i.e. when a broad band light is used, part of the light will pass through the gratings and part of it will be reflected at a specific wavelength unique to that FBG. When damage is present close to the FBG, there will be changes in the reflected spectrum in terms of its intensity and wavelength. These changes can then be converted into strain measurements (axial only). Therefore, FBG sensors are very attractive strain sensors due their high sensitivity ($\mu$e).

**System principles**

The hybrid SHM system uses the PZT actuators to input a controlled excitation to the structure while the FO sensors are used to capture the corresponding response, see Figure 1. The diagnostic
hardware consists of an Arbitrary Wave Generator (AWG) to excite the PZT actuator. A photodetector is then used to record the response of the FBG sensors. The tuneable laser is used as a light source and set to deliver monochromatic light to the array of gratings. Optical signals that travel in opposite directions are separated with the circulator: only the light reflected from the FBG is measured by the photodetector. The intensity of the reflected light from the sensor is spectrally filtered and converted to voltage. As the strain on the FO sensor changes in time (due to the propagating Lamb wave), the reflected light intensity shifts up and down and causing a varying voltage signal in time domain.

**Experimental setup**

To validate the hybrid system introduced in the previous section, an experiment was set up to detect guided waves in a thick composite skin/stringer part as shown in Figure 2. Three surface mounted PZT transducers were used for exciting and recording the generated guided waves together with three FBG sensors surface mounted on the stringer as sensors.

Damage was simulated by adding mass in 4 different locations: states ST1-3 at the foot of the stringer while for state ST4 damage was located on the stringer, see Figure 3. The first step was measure pristine signals, exciting the structure with a 5-cycle Hanning window signal centred at 300 kHz and recording the response in both PZT and FBG sensors. Then the damage state was represented by adding mass at different locations and the sensor responses recorded again. The FBG sensors have low signal-to-noise ratio so it requires filtering and averaging to obtain precise results. The FBG sensors responses were filtered using both bandpass and Butterworth filters and averaged 1000 times to get rid of noise. The sensor signals from pristine state and damage states are then compared to identify whether the changes in the propogational properties of the wave can be used to detect and identify damage.
Three different actuators were used were exciting the structure as indicated by red circles in Figure 3. PZT 1 is attached to the composite skin, while PZTs 2 and 3 are mounted on the stringer. All the FBG sensors are also mounted on the stringer. The first test is to simulate damage at the foot of the stringer (ST1:3) and to investigate whether the FBG sensors on the stringer will experience any change due to this damage. The results of actuation at PZT1 and sensing in FBG 1-3 are presented in Figure 4. It can clearly be seen that the path PZT1-FBG2 which goes directly through damage has a noticeable change in the signal (amplitude drop) which is to be expected for Lamb waves going directly through a damage zone. It is worth mentioning that in this case, the FBG2 records the signal perpendicular to its grating. The FBGs have the highest sensitivity for strain reading in the actual direction.

For damage states 2 and 3 similar results were observed. The signals actuated by PZT1 and recorded by FBGs 1-3 are presented in Figure 5. The same behaviour can be observed; when the signal goes through the direct pass (PZT1-FBG1) there is amplitude reduction. However in this case, since the direction of propagation is neither parallel nor perpendicular to the FBG, the effect of damage is seen on the later modes rather than the first mode.
For damage state 4 when the mass was located between FBGs 2 and 3 a significant change was observed in FBG3 while no changes were observed in FBGs1 and 2. In this case PZT2 was used as the actuator and it can be observed that when both actuator and sensor are on the stringer a much clearer change is observed due to presence of damage in the direct path. In addition, PZT2 sends strain waves in the direction of the FBGs which are most sensitive to strain measurements, see Figure 6 (a). The response of FBG3 was then compared to PZT3 presented in Figure 6 (b). It can be seen that the changes in the PZT 3 due to presence of the damage on the direct path is much smaller than the changes in the signal recorded by FBG3. This confirms the higher strain sensitivity and the advantage of the hybrid system.

Figure 6 Lamb wave signals - pristine vs damage for damage state 4

Conclusion

In this paper a hybrid SHM system for damage detection is proposed which uses the advantages of both PZT actuators and FBG sensors. An experimental set up was designed to check the response of the FBG sensors against PZTs for detecting artificial damage in a thick composite skin/stringer part. The results show very good detectability for the hybrid system for damage detection in complex parts.

Acknowledgment: The research leading to these results has gratefully received funding from the European JTI-CleanSky2 program under the Grant Agreement n° 314768 (SHERLOC).

References


