LAMB WAVE BASED STRUCTURAL HEALTH MONITORING USING FIBRE BRAGG GRATING-BASED INTRINSIC FABRY-PEROT INTERFEROMETER SENSOR

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang Al-Sultan Abdullah or any other institutions.

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ABSTRAK

Keperluan untuk meningkatkan tahap keselamatan dan pengurangan kos penyelenggaraan sesuatu struktur boleh dicapai dengan menggunakan sistem pemantauan yang boleh diyakini iaitu pemantauan kesihatan struktur (SHM). Bagi struktur yang mempunyai ketebalan nipis, aplikasi gelombang Lamb untuk sistem SHM ini sangat diperlukan kerana kelebihannya berbanding pendekatan lain. Gelombang Lamb ialah gelombang kenyal yang mempunyai sifat penyebaran yang merambat di dalam plat dan struktur seperti kelompang. Kerosakan pada sesuatu struktur dapat dikesan dengan menggunakan maklumat daripada saling tindak antara gelombang Lamb dan kecacatan pada struktur. Saling tindak ini dapat dilihat sebagai pantulan dan penukaran mod Lamb. Perubahan dalam isyarat gelombang Lamb diekstrak untuk mengesan kerosakan dalam struktur yang dipantau. Saling tindak ini adalah kompleks. Oleh itu, penderia yang mempunyai kepekaan yang lebih tinggi diperlukan untuk merakam saling tindak gelombang Lamb untuk aplikasi dalam sistem SHM. Kerja yang dibentangkan ini mencadangkan penderia gentian optik iaitu penderia FBG-IFPI untuk merakam isyarat gelombang Lamb. Keupayaan penderia ini untuk mengesan sebarang kecacatan diuji dengan menggunakan prosedur ujikaji. Penderia ini adalah hibrid antara penderia *Bragg grating* dan penderia *Fabry-Perot interferometer*. Kesan daripada perubahan panjang rongga optik, kepekaan terhadap arah, dan terikan dinilai menggunakan ujikaji. Hasil yang positif telah diperolehi daripada penilaian tersebut. Bagi ujikaji yang melibatkan perubahan panjang rongga optik, keputusan menunjukkan bahawa rongga optik yang panjang memberikan nilai kepekaan yang lagi tinggi berbanding rongga optik yang pendek. Penderia FBG-IFPI dengan rongga optik sepanjang 10 mm mempunyai nilai free spectral range (FSR) sebanyak 83 pm, manakala penderia yang mempunyai rongga optik sepanjang 20 mm memberikan nilai FSR sebanyak 34 pm. Nilai FSR yang lebih kecil menunjukkan nilai kepekaan dan peleraian yang lebih tinggi iaitu sebanyak 2.46 kali lebih tinggi bagi kajian ini. Penderia FBG-IFPI berada pada prestasi yang maksimum apabila berorientasikan dalam arah jejarian (0°) daripada sumber gelombang Lamb, yang mana menunjukkan peningkatan amplitud sebanyak 75% berbanding ketika berorientasi pada sudut bertentangan (± 90°). Selain itu, prestasi penderia FBG-IFPI dalam pengesanan terikan dapat ditingkatkan dengan mengenal pasti panjang gelombang yang optimum. Panjang gelombang ini akan memaksimumkan kepekaan penderia. Hasil kajian menunjukkan peningkatan kepekaan sebanyak 7.4% berbanding kepekaan terikan penderia FBG biasa. Selain itu, peningkatan prestasi penderia juga boleh diamati menggunakan nilai kecerunan mutlak yang mana menunjukkan kepekaan sebanyak 7.5 kali lebih tinggi daripada penderia FBG. Penderia FBG-IFPI dipasang pada dua struktur yang berbeza iaitu permukaan plat yang utuh dan permukaan plat yang rosak pada dua kedudukan iaitu 8 dan 23 cm daripada penggerak. Kedudukan penderia ini mewakili kaedah *pulse-echo* dan *pitch-catch*. Hasil daripada analisis yang dilakukan menggunakan data daripada kaedah *pulse-echo*, didapati terdapat paket gelombang tambahan yang terhasil daripada pantulan pada struktur yang rosak. Sementara itu, bagi kaedah pitch-catch, didapati terdapat penurunan nilai amplitud sebanyak 66% berbanding dengan data plat yang utuh. Ciri-ciri ini merupakan ciri yang boleh digunakan untuk mengesan kerosakan pada struktur plat apabila menggunakan penderia FBG-IFPI semasa proses pemantauan sistem. Ciri-ciri ini juga telah berjaya disahkan dengan menggunakan kaedah finite element analysis (FEA). Dapatan ini menunjukkan kebolehgunaan penderia yang dicadangkan dalam pengesanan kerosakan, yang boleh digunakan sebagai penderia alternatif untuk aplikasi SHM

ABSTRACT

The demand for an increase in structural safety and a reduction in structural maintenance costs can be achieved by applying a reliable monitoring system. Such systems are called structural health monitoring (SHM) systems. There are several SHM techniques suitable for engineering structures such as acoustic emission (AE), electromechanical impedance (EMI) or Lamb waves testing. The applications of Lamb waves for SHM systems are highly desirable owing to their advantages compared to other approaches. Lamb waves are elastic waves having dispersive behaviours that propagate in plates and shell-like structures. The detection of damage comes from the interaction of Lamb waves with defects in the structures. These defects triggered reflections and conversions of the Lamb modes. The changes in the Lamb wave signals are extracted to detect the damage in the monitored structure. These interactions are complex. Thus, a higher sensitivity sensor is required to capture the interaction of the Lamb wave for applications in SHM systems. The present work proposed an optical fibre sensor, fibre Bragg grating-based intrinsic Fabry-Perot interferometer (FBG-IFPI) sensor for damage detection using Lamb wave technique. It is a hybrid of the fibre Bragg grating sensor and the Fabry-Perot interferometer sensor. The effect of the variation of optical cavity length, the directional sensitivity, and the response of the sensor towards the strain were evaluated. A positive result was observed from that evaluation. It was found that the sensitivity was higher for the longer optical cavity length. The FBG-IFPI with a 10 mm optical cavity length has an FSR of 83 pm, while FBG-IFPI with a 20 mm optical cavity length has an FSR of 34 pm. A smaller FSR indicates a steeper edge and yields a higher strain on optical power amplification, which presents higher sensitivity and resolution in the sensing. The result shows that the sensitivity enhancement in the longer optical cavity is 2.46 times higher. The FBG-IFPI sensor was at its maximum performance when it was oriented in the radial direction (0°) of the source Lamb wave, which shows an increment of 75% for amplitude detection compared to when it is oriented at the right angle with the radial direction (± 90°). In addition, the sensor performance in strain sensing was improved by identification of the optimum wavelength. This wavelength would maximise the sensitivity of the sensor to small changes in strain. It shows an increment of about 7.4% compared to the strain sensitivity of the single FBG. Other than that, the improvement of the FBG-IFPI sensor can also be observed using the absolute gradient curve, which shows the sensitivity is 7.5 times higher than the FBG sensor. The FBG-IFPI sensor was surface mounted on the intact and damaged plate. The sensor was placed at two different positions, that is, 8 and 23 cm from the actuator, which represent the pulse-echo and pitch-catch methods. For the pulse-echo method, additional wave packets are observed due to the reflection from the defect. Meanwhile, for the pitch-catch method, the observation of the amplitude decrements was 66% compared to the intact plate signal. The characteristics of the Lamb waves during interaction with defects for the two methods were successfully detected by the FBG-IFPI sensor and they were validated by Finite Element Analysis (FEA). For the pulse-echo method using FEA, the finding shows that there is also one additional wave packet that appears after the wave interacts with the defect. The analysis of the pitch-catch method shows about 76% amplitude decrement. These characteristics are the damage features that can be used as an indicator for the structure health status. Thus, the main results of the work presented here are the extracted damage indicator from the measured signal using the proposed sensor. This finding shows the applicability of the proposed sensor in damage detection, which can be utilised as the alternative sensor for SHM applications.

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