IMPROVED STATIC AND DYNAMIC FBG SENSOR SYSTEM FOR REAL-TIME MONITORING OF COMPOSITE STRUCTURES

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Master

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science in Mechanical engineering.

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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 or any other institutions.

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LIST OF SYMBOLS

λ_B	Bragg wavelength
°C	Celcius
$\Delta\lambda_B$	Change of Bragg wavelength
ΔT	Change of temperature
Δt	Change of time
κ	Grating orders
η_{eff}	Grating refractive index
Cg	Group of velocity
Λ_o	Initial grating period
μ	Micro
%	Percent
η_o	Refractive index
Fs	Sampling frequency
ε	Strain
â	Thermal expansion
ξ	Thermo-optic coefficient

LIST OF ABBREVIATIONS

AE	Acoustic emission
ASE	Amplified spontaneous emission
BVID	Barely visible impact damage
CO_2	Carbon dioxide
CFRP	Carbon fibre reinforced plastic
cm	Centimetre
m^3	Cubic metre
dB	Decibel
EMI	Electromagnetic interference
ET	Electromagnetic testing
FP	Fabry-perot
FFT	Fast Fourier Transform
FBG	Fibre Bragg grating
FOS	Fibre optic sensor
FRP	Fibre-reinforced polymer
Ge	Germanium
GFRP	Glass fibre reinforced plastic
g	Gram
GUI	Graphical user interface
Hz	Hertz
InGaAs	Indium-Gallium-Arsenide
JSCE	Japan Society of Civil Engineers
kg	Kilogram
kHz	Kilohertz
km	Kilometre
kPa	Kilopascal
LCCA	Life-Cycle Cost Assessment
MHz	Megahertz
MPa	Megapascal
MEMS	Micro-electromechanical systems
µm	Micro-metre
µε	Micro-strain
mm	Millimetre
ms	Millisecond

mV	Millivolts
nm	Nanometer
N	Newton
NOx	Nitrogen oxides
NDE	Non-destructive evaluation
NDT	Non-destructive testing
OSA	Optical spectrum analyser
PD	Photodetector
Pe	Photo-elastic
pm	Picometre
POF	Plastic-based optical fibre
PTFE	Polytetrafluoroethylene
PVDF	Polyvinylidene fluoride
PLC	Programmable logic controller
RT	Radiographic testing
s	Second
SMA	Shape memory alloy
SMP	Shape memory polymer
SNR	Signal to noise ratio
Si	Silicon
SHM	Structural health monitoring
SLD	Superluminescent diode
UT	Ultrasonic testing
UV	Ultraviolet
VT	Visual testing
V	Volts

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ABSTRAK

Gentian kaca polimer (GFRP) adalah sejenis bahan komposit yang memiliki nisbah kekuatan yang tinggi terhadap keseluruhan berat berbanding dengan bahan logam konvensional. Namun begitu, bahan komposit ini mudah terdedah kepada kerosakan yang mana memerlukan pemantauan keadaan struktur objek tersebut. Penderiaan FBG mempunyai potensi yang tinggi untuk disatukan dengan bahan komposit dalam perlaksanaan permantauan berterusan kondisi struktur objek. Namun begitu, kajian mendapati sistem permantauan berdasarkan FBG dilihat mepunyai beberapa kelemahan dari segi statik dan juga dinamik. Variasi dari keluaran voltan menyebabkan bacaan yang tidak tepat. Kaedah ilustrasi spektrum dalam pentafsiran statik juga dikenalpasti sebagai kelemahan dalam pengukuran statik. Bagi kelemahan dalam pengukuran dinamik, kesukaran dalam perbezaan masa antara dua isyarat menyebabkan anggaran sumber isyarat yang tidak tepat. Justeru, tujuan utama kajian penyelidikan ini adalah untuk meningkatkan serta penambahbaikkan dalam sistem permatauan berdasarkan FBG dengan penggunaan fungsi dan algoritma tertentu seperti fungsi grid jaring, algoritma penormalan voltan, algoritma CC-LSL, dan fungsi FFT. Dua spesimen telah dibentuk iaitu plat komposit dan rasuk komposit yang berasaskan kaedah laminasi. Penderiaan FBG telah diintegrasikan ke dalam kedua-dua spesimen tersebut. Bagi penambahbaikkan dalam permantauan secara statik, kedua-dua specimen tersebut dikenakan beban. Secara hasilnya, fungsi grid jaring digunakan sebagai paparan interaktif yang mewakili struktur objek berkenaan dan akan memaparkan kondisi struktur semasa berlaku pesongan. Algoritma penormalan voltan pula berjaya mengurangkan variasi keluaran voltan dari 26 data/minit kepada 17 data/minit. Bagi penambahbaikkan dalam permantauan secara dinamik pula, kesan penyetempatan dijalankan ke atas rasuk pada tempat tertentu. Secara hasilnya, algoritma CC-LSL mampu membuat anggaran impak secara tepat dengan peratusan kesilapan pada 2.47% dari impak sebenar. Perbandingan spektrum frekuensi antara sensor FBG dan sensor AE pula menunjukkan profil yang sama dengan peratusan kesilapan keseluruhan kurang daripada 10%. Manakala perbandingan spektrum frekuensi antaran sensor FBG, sensor AE, dan simulasi dari Abaqus FEA menunjukkan sensor FBG lebih sensitif kepada gelombang perambatan normal mod berbanding dengan sensor AE. Sensitiviti statik dan dinamik kesuluruhan sensor FBG ini direkodkan pada 1.21 pm/$\mu\varepsilon$ dan mampu mentaksir frekuensi maksima pada nilai 5 kHz. Secara kesimpulan, dipercayai bahawa sistem bereputasi ini mampu mencapai konsep utama struktur pintar.

ABSTRACT

Glass-fibre reinforced polymer (GFRP) composite materials certainly have the undeniable favour over conventional metallic materials, notably in light weight to high strength ratio. However, these composite materials are prone to sudden catastrophic damage that requires the structural health monitoring (SHM). FBG sensor has shown a great potential in embedding and integrating with the composite materials, performing real-time monitoring of the structural condition. However, a critical review on the current FBG based real-time monitoring system initiates that many attempts and intentions are still needed to bring the present monitoring system to a fully matured readiness level. The main problems are the drawbacks in static and dynamic strain sensing monitoring assessment. Error in desired readings due to variations in output voltage and spectrum illustration for static strain interpretation are the drawbacks in static strain sensing. On the other hand, due to the presence of noise in the signal spectrum, the estimation of time of arrival (TOA) through peak detection is pin-pointed as the drawback in dynamic strain sensing. Thus, the designation of this research study is to improve the current FBG based real-time monitoring system with the use of certain functions and algorithms, that are the instant mesh-grid function, voltage normalization algorithm, CC-LSL algorithm, and FFT function. Two specimens have been fabricated namely composite plate and composite beam which are based on hand lay-up lamination method. FBG sensors are embedded in both the structures. For improvement in static strain measurement, both the specimens are being subjected to load induced. As a results, the mesh-grid function utilized is capable of meshing any sizes and shapes of a structure, and display the deflection of the structure in an interactive way of artificial representation. The voltage normalization algorithm has reduced the output voltage variations from 26 data/minute to 17 data/minute with the elimination of pre-calibration each time before use. For the improvement in dynamic strain sensing, impact localization are being carried out on the beam at certain points. As a results, the merging of cross-correlation approach with linear source location technique (CC-LSL) has estimated the impact location close to the actual hit location with the largest relative error at only 2.47 %. The comparison of frequency spectrum between FBG sensor and AE sensor shows an identical profile with the percentage error of less than 10 %. The validation of frequency spectrums from FBG sensor and AE sensor with Abaqus FEA simulation shows that the frequency spectrums captured by FBG sensor are more sensitive to the normal mode wave propagation of the structure compared to AE sensor. Overall, the static and dynamic sensitivity of the FBG sensor was recorded at 1.21 pm/με with maximum capturing frequency of 5 kHz. From the conclusion of the study, it is truly believed that with this reputable sensing system, it is is one step closer to achieving the key concept of smart structure.

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