DEVELOPMENT OF A NON-INERTIA MASS FIBRE BRAGG GRATING ACCELEROMETER BASED ON A SINGLE DIAPHRAGM MECHANISM AND ITS VIBRATION RESPONSE ANALYSIS

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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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ABSTRAK

Pembangunan penderia gentian parutan Bragg (FBG) sebagai sebuah penderia pecutan telah mendapat perhatian yang besar memandangkan penderia FBG amat peka terhadap terikan. Pengenalan jisim inersia ke dalam pecutan FBG jenis diafragma meningkatkan kerumitan mekanisme pecutan. Selain itu, kajian berangka dan eksperimen tidak dilaporkan dan diterbitkan secara komprehensif, walaupun beberapa aspek penderia pecutan perlu disiasat dengan teliti. Objektif keseluruhan tesis ini adalah untuk membentangkan reka bentuk baharu penderia pecutan FBG jisim bukan inersia (FBGA-SD) jenis diafragma yang kecil dan boleh fabrikasi yang didatangkan dengan ciri baharu, serta analisis berangka dan eksperimen yang komprehensif. Penyelidikan ini bermula dengan pembangunan lima reka bentuk FBGA-SD dan pemarkahan konsep mereka. Dinamik reka bentuk FBGA-SD yang akhir kemudiannya dikaji menggunakan analisis modal unsur terhingga diikuti dengan analisis tindak balas harmonik untuk menentukan lokasi terikan maksimum pada diafragma untuk meletakkan penderia FBG. Kefungsian FBGA-SD akhirnya dikaji melalui analisis tindak balas sementara dan kerja eksperimen serta penentuan kepekaan. Reka bentuk akhir FBGA-SD dengan dimensi 16 mm × 16 mm × 10 mm dan berat 4-gram telah menghapuskan kelemahan empat reka bentuk FBGA-SD sebelumnya, dengan ciri-ciri baru diperkenalkan terutamanya dalam pemanjangan terowong FBG dan ciptaan lubang telus untuk memantau penderia FBG di dalam poket diafragma. Analisis modal unsur terhingga telah memastikan bahawa frekuensi semulajadi pertama diafragma adalah lebih rendah (13, 380 Hz) dan jauh daripada perumah (20, 689 Hz) untuk mengelakkan dinamik perumah yang menjejaskan tindak balas penderia pecutan. Lokasi terikan maksimum untuk meletakkan penderia FBG pada diafragma ditentukan, dengan dua kedudukan terbaik didapati berada di tengah dan di sepanjang tepi diafragma. Disebabkan fakta bahawa pinggir diafragma adalah kawasan yang diapit, meletakkan penderia FBG di tengahnya adalah lebih sesuai. Tindak balas anjakan panjang gelombang yang diperolehi daripada analisis tindak balas sementara dan eksperimen menunjukkan persetujuan yang baik dari segi corak dan fasa, tetapi berbeza sebanyak 50% dari segi amplitud. Didapati juga bahawa pecutan asas dan anjakan panjang gelombang kedua-duanya menunjukkan bahawa ianya adalah juga sefasa. Perbezaan 50% dalam amplitud anjakan panjang gelombang mencerminkan kepekaan FBGA-SD, di mana kepekaan eksperimen ialah 9.64×10^{-5} nm/g dan analisis tindak balas sementara memberikan 4.79×10^{-5} nm/g, sah untuk julat frekuensi pengujaan 10 hingga 147 Hz dan pecutan asas maksimum 10.5 m/s^2. Dalam julat ini, kepekaan tidak bergantung kepada frekuensi.

ABSTRACT

The development of the fibre Bragg grating (FBG) sensor as an accelerometer has received considerable attention since the FBG sensor is remarkably sensitive to strain. The inclusion of inertia mass in the diaphragm-type FBG accelerometer increased the complexity of the accelerometer mechanism. Moreover, numerical and experimental studies are not comprehensively reported and published, despite the fact that several accelerometer aspects should be thoroughly investigated. The overall aim of this thesis is to present a new design of a small and fabricable, diaphragm-type non-inertia mass FBG accelerometer (FBGA-SD) that comes with new features, as well as its comprehensive numerical and experimental investigation. This research begins with the development of five FBGA-SD designs and their concept scoring. The dynamic of the final FBGA-SD design is then investigated using finite element modal analysis followed by harmonic response analysis to determine the location of maximum strain on the diaphragm to place the FBG sensor. The functionality of the FBGA-SD is finally investigated through transient response analysis and experimental work as well as sensitivity determination. The final design of FBGA-SD with dimensions of 16 mm × 16 mm × 10 mm and a weight of 4 grammes has eliminated the weaknesses of the previous four FBGA-SD designs, with new features introduced particularly in the lengthening of the FBG tunnel and the invention of a through-hole for monitoring the FBG sensor inside the diaphragm pocket. Finite element modal analysis has ensured that the first natural frequency of the diaphragm is low (13, 380 Hz) and far from that of the housing (20, 689 Hz) in order to avoid the dynamic of the housing affecting accelerometer response. The location of the maximum strain for placing the FBG sensor on the diaphragm is determined, with the two best positions found to be in the middle and along the edges of the diaphragm. Due to the fact that the edge of the diaphragm is a clamped area, positioning the FBG sensor in its middle would be ideal. The response of the wavelength shift obtained from transient response analysis and experiment agrees well in terms of pattern and phase but differs by 50% of amplitude. It should also be mentioned that the base acceleration and the wavelength shift both demonstrate that they are in the same phase with one another. The 50% difference in amplitude of the wavelength shift reflects the sensitivity of the FBGA-SD, where the experimental sensitivity is 9.64×10^{-5} nm/g and the transient response analysis gives 4.79×10^{-5} nm/g, valid for the range of excitation frequencies of 10 to 147 Hz and maximum base acceleration of 10.5 m/s^2. Within these ranges, the sensitivity is not frequency dependent.

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a	Radius of the diaphragm
A	Area of the diaphragm
d_{max}	Deformation maximum
E	Young's modulus
h	Thickness of the diaphragm
g	Gravitational acceleration
i,j	Nodal diameters
Hz	Hertz
L_g	Length of the grating FBG sensor
L_T	Length of the tunnel FBGA-SD
N	Newton
r	Length measured from centre diaphragm
R	Radius of the hole
THRU	Through hole
V	Volume
λ_B	Bragg wavelength
$\Delta\lambda_B$	Change of Bragg wavelength
Λ	Grating period
ρ	Density
ρ_ε	Strain-optic coefficient
α_f	Thermal expansion coefficient
ξ	thermal-optic coefficient
ε	Strain
ε_{FBG}	Strain of the FBG sensor
ε_{max}	Strain maximum
n_{eff}	Effective refractive index
$\lambda^2_{i,j}$	Dimensionless natural frequency parameter
γ	Mass per unit area
ν	Poisson's ratio of diaphragm
⌀	Diameter of the hole
↧	Depth of the hole

$\Delta\varepsilon$	Change of strain
ΔT	Change of temperature
$\Delta\lambda_B$	Change of Bragg wavelength

LIST OF ABBREVIATIONS

3D	Three-dimensional
3D-FE	Three-dimensional finite element
BLS	Broadband light source
CAD	Computer aided drawing
CNC	Computer Numerical Control
DAQ	Data Acquisition
dB	Decibel
EDM	Electro discharge machine
EMI	Electromagnetic interference
FBG	Fibre Bragg grating
FBGA-DD	Fibre Bragg grating accelerometer double diaphragms
FBGA-SD	Fibre Bragg grating accelerometer single diaphragm
FBGIA	Fibre Bragg grating Interrogation analyser
FE	Finite element
FEA	Finite element analysis
G-code	Geometry-code
GPa	Gigapascal
KHz	Kilohertz
kS/s	Kilo samples per second
M2	Metric thread of 2 mm
M5	Metric thread of 5 mm
mm	Millimetre
mV/g	Millivolt per gravitational acceleration
mW	Milliwatt
m/s^2	Acceleration
nm	Nanometre
nm/g	Nanometre per gravitational acceleration
PLA	Polylactic acid
PSRF	Product of the sensitivity and natural frequency
pm/g	Picometre per gravitational acceleration
pm/με	Picometre per micro strain

SDOF	Single degree of freedom
SLSR	Side lobe suppression range
STL	Standard Triangle Language
Ti-6Al-4V	90% titanium, 6% aluminium, 4% vanadium,
UV	Ultraviolet
v1	FBGA-SD first design
v2	FBGA-SD second design
v3	FBGA-SD third design
v4	FBGA-SD fourth design
v5	FBGA-SD fifth design
$\mu\varepsilon/g$	Micro strain per gravitational acceleration

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