UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF WIRELESS STRUCTURAL HEALTH MONITORING SYSTEM FOR OIL AND GAS PIPELINES

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

July 2019

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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July 2019

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Damage detection and life prediction of structures are important technological issues in both the academic and industrial fields. Numerous techniques have been proposed and developed for the detection of early damage in structural members. Research shows that periodical or visual inspections will not help resolve these issues, rather, having a continuous monitoring system is required for a particular system such as NPP (Nuclear Power Plant). Currently, Non Destructive Inspection (NDI) is used to inspect the area, however this can only be done in offline mode. Structural Health Monitoring (SHM) offers various methods to resolve issues such as these, nonetheless smart detecting methods are required before major failures occur, in order to avoid catastrophic failures in future. SHM can monitor this situation in active and passive states, either by online or offline monitoring. The use of SHM is to augment the NDI application and not to replace it. Then, the costs of a wired detecting system is high per channel, and requires focus on a wireless detecting method to reduce costs and avoid direct contact with hazardous areas. The main objective of this research is to develop of a wireless system or device embedded with a smart PZT sensor to detect flaws and structural defects on a selected investigated structure. Smart PZT sensors were used as an actuator and sensor, coupled with two XBees and one signal generator IC chip. The programme execution on the transmission and receipt of the ultrasonic guided wave via the PZT sensor was written in MATLAB. Basically, the developed source code is to receive serial data from one Xbee to another remote Xbee which is attached to the investigated structural system. The refined waveform response is utilised in an undergoing prognosis of the true structural status. The 4mm simulated hole on the pipe structure is benchmarked against its pristine condition in validating the effectiveness of the developed SHM wireless module. A marker plot software and Arduino micro controllers was used in wireless module for a further analysis and interpretation of results. The acquired results showed that no change for the pattern of wave in non-defected areas and despite being

disrupted in the affected areas. The guided waves from wireless SHM system are able to propagate long distances and reach difficult access regions, hence the ultrasonic waveform device are continuously increasing for non-destructive evaluation and structural health monitoring in various structural applications.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN SISTEM PENGAWASAN KESIHATAN STRUKTUR (SHM) TANPA WAYAR UNTUK TALIAN PAIP MINYAK DAN GAS

Oleh

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Pengesanan kerosakan dan ramalan hayat bagi struktur adalah isu teknologi penting dalam bidang akademik dan industri. Banyak teknik telah dicadangkan dan dibangunkan untuk mengesan kerosakan awal dalam struktur-struktur. Pemeriksaan berkala dan pemeriksaan visual tidak akan membantu menyelesaikan masalah ini. Sedangkan sistem pemantauan berterusan diperlukan untuk sistem tertentu seperti NPP (loji kuasa nuklear). Pada masa ini, Pemeriksaan Tanpa Musnah (NDI) digunakan untuk memeriksa kawasan tersebut, namun ini hanya boleh dilakukan dalam mod luar talian. Sistem pengawasan kesihatan struktur (SHM) menawarkan banyak kaedah untuk menyelesaikan masalah ini. Tetapi masih kaedah pengesan pintar diperlukan untuk menyelesaikan masalah sebelum ia membawa kepada kegagalan utama. Jadi pada masa akan datang, ini membantu kita untuk mengelakkan kegagalan bencana. SHM boleh memantau keadaan ini dalam keadaan aktif dan pasif, sama ada melalui pemantauan dalam talian atau luar talian. Penggunaan SHM adalah untuk menambah aplikasi NDI dan bukan menggantikannya. Sistem pengesan berwayar akan dikenakan kos tinggi setiap saluran dan diperlukan untuk memberi tumpuan kepada kaedah mengesan tanpa wayar untuk mengurangkan kos dan mengelakkan sentuhan langsung dengan kawasan berbahaya. Tujuan utama penyelidikan ini adalah untuk membangunkan dan menhasilkan peranti tanpa wayar yang lebih baik yang menggunakan sensor PZT pintar untuk mengesan kecacatan dan kerosakan pada struktur yang diselidik. Sensor PZT pintar telah digunakan sebagai penggerak dan sensor, ditambah dengan dua cip IC penjana isyarat XBee dan. Pelaksanaan program untuk menghantar dan menerima gelombang berpandu ultrasonik melalui sensor PZT telah ditulis dalam MATLAB. Kod sumber yang dibangunkan pada asasnya adalah untuk menerima data bersiri dari satu Xbee ke satu lagi Xbee jauh yang dilampirkan kepada sistem struktur yang diselidiki. Tindak balas gelombang yang diperhalusi digunakan dalam menjalani prognosis status struktur yang benar. Lubang 4 mm yang

diselaraskan pada salah satu struktur paip ditanda aras dalam mengesahkan keberkesanan modul SHM tanpa wayar yang dibangunkan. Perisian Marker Plot dan pengawal mikro Arduino digunakan dalam modul tanpa wayar untuk analisis lanjut dan tafsiran hasil. Hasil yang diperoleh menunjukkan bahawa tiada perubahan pola corak di kawasan tidak bertentangan dan walaupun terganggu di kawasan yang terjejas.Hasil yang diperoleh menunjukkan bahawa gelombang lebih banyak walaupun di kawasan yang tiada kerosakan manakala terganggu di kawasan yang terjejas. Gelombang ultrasonic dari system SHM tanpa wayar akan terus meningkat untuk penilaian tidak menentu dan pemantauan kesihatan struktur dalam pelbagai aplikasi struktur kerana alat gelombang berpandu boleh menyebarkan jarak jauh dan mencapai kawasan sukar.

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude to my advisor, Prof. Ir. Dr. Faizal Mustapha for the continuous support of my Ph.D study and related research for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my Doctorate of Philosophy study.

Besides my advisor, I would like to thank the rest of my members of supervisory committee: Assoc. Prof. Ir. Dr. Kamarul Arifin Ahmad and Assoc. Prof. Dr. Faieza binti Abdul Aziz for their insightful comments and encouragement, but also for the hard question which incented me to widen my research from various perspectives.

I thank my fellow colleagues for the stimulating discussions, for the sleepless nights we were working together before deadlines, and for all the fun we have had in the last years in pursuing this study, in particular. Last but not the least, I would like to thank my family, my wife for standing beside me and who encourage me to complete my study, from deep of my heart I thank you and my loving children for being patience with me, my parents and siblings for supporting me spiritually throughout writing this thesis and my life in general.

THANK YOU

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

NDI	Non-Destructive Ispection
NDT	Non-Destructive Testing
PZT	Lead Zincornate Titanate
SHM	Structural Health Monitoring
V_{PP}	Voltage Peak-to-Peak

CHAPTER 1

INTRODUCTION

This first chapter of this thesis presents the research background and the current challenges faced by the various industries, particularly in the oil and gas industry. The objectives, scopes of research, as well as the problem statement are included in this chapter.

1.1 Research Background

Delamination, disbanding, void, low impact resistance and visible internal damage are the types of damages that can be uniquely found in the structure. Any damage found on the structure requires repair, therefore an inspection needs to be done to detect any form of damage on the structure. Both the Non-Destructive Inspection (NDI) and Structural Health Monitoring (SHM) concepts have been used to detect flaws from structures. However, the SHM concept is a contrast from the NDT, wherein the framework is used to screen the trustworthiness of mechanical structures consistently and independently. SHM can further reduce maintenance costs. SHM can also monitor situations in either active and passive states, whether via online or offline monitoring. The use of SHM is to augment the NDI application and not to replace it.

Structural Health Monitoring (SHM) is defined as the "acquisition, validation and analysis of technical data to facilitate life cycle management decisions" (Sohn et al., 2001). SHM indicates a framework with the capacity to recognise and translate unfavourable "changes" in a structure to enhance unwavering quality and decrease Life Cycle Costs (LCC) (Farrar et al., 2007). The most essential test in outlining a SHM framework is realising what "changes" to search for and how to distinguish them. The qualities of harm on the specific structures assume a key part in characterising the engineering of the SHM framework. The subsequent "changes" or harm directs the kind of sensors that are required. This will ultimately lead to the decision on the necessity of the leftover parts in the framework.

The present research project concentrates on the use of Lead Zirconate Titanate (PZT) sensors on the structural parts. The sensors are used to detect any change in the behaviour of the materials. Others types of sensor have been cited throughout the literature such as the Fiber Bragg Grating (FBG), non-contact laser, Comparative Vacuum Monitoring (CVM), Shape Memory Alloy (SMA) and others. These sensors detect structural anomalies through a variety of techniques which have different advantages over the others. PZT sensors are chosen due to their versatility, conformability, low power consumption and high bandwidth.

Piezoelectric transducers or sensors have the capability of transforming mechanical energy to electrical energy and vice versa. SHM involves the integration of sensors, data transmission, probably smart materials, computational power, and handling out ability inside the structures. Because of this capability, it makes it possible to reconsider the design and the full management of the structure.

Normally, as part of recognising the ordinary and harm state of the tried structure, a vast majority of checking gadgets use links and non-constant information mode, and subsequently post handled by utilising SHM calculation (Mustapha et al., 2007). Once in a while, the cabling medium can be ‘unpredictable’ where it will then require over-the-top labour which can thereafter lead to tremendous costs. One of the techniques to overcome this impediment is by setting up gadget alleged remote sensor hubs that can screen the structure at any time and place without human intercession for a long period of time. This gadget is utilised to transmit and obtain sensor information in a constant mode and to perform flag examinations over the tried structures. A broad study has been done to guarantee the viability and capacity of this gadget where for all intents and purposes it has to suit to the operation and condition over a guaranteed or determined timeframe. A few issues emerged during the building up of this remote gadget which need further investigation, namely, the parameters of vitality sources, control utilisation and operation strategy.

1.2 Problem Statement

SHM is widely used in worldwide engineering applications. Currently, the water or oil and gas industry as example is geared towards using SHM systems to tap their benefits in order to effectively detect damage. A single malfunction or damage either in the structure or the system will lead to catastrophic or fatal failures. Results of the investigations show that the average LCCs pipelines are spent on inspection and repair, not including the costs associated with unscheduled maintenance visits and defect rectification for inspection. For example, in the oil and gas industry, economics of events such as these can easily lead to circumstances where hefty costs are involved in ensure the pipelines’ readiness for their intended operation.

Although NDI is the best practice for detecting structure damage, it is time consuming and requires increased man hours. A single technique may not be feasible to conclude the findings. As such, additional inspection methods are required to confirm the defects as the damage is very much related to the type of inspection, the level of the inspectors and the type of equipment involved.
In order to improve detectability of damage in the composite structure, Structural Health Monitoring (SHM) techniques have been developed. Similar to NDIs, SHM consists of several types of sensors, which depend on their active/passive acquisitions and online/offline interrogation functions. An ideal SHM system takes advantage of active-online in which continuous information can be retrieved and processed for evaluation.

Based on the literature review, we observe that on average, industries spend on inspection and repair, not including costs associated with unscheduled maintenance visits and defect rectification. As mentioned above, economics of this event in the industry can lead to heavy costs to ensure the pipelines maintain in good condition.

1.3 Research Objectives

Overall, the objectives of this research are to acquire the Structural Health Monitoring response from an experimental structural integrity point of view, by using multivariate statistical analysis. The specific objectives of this research are:

1. To develop Wireless Structural Health Monitoring System which can detect damage or crack in online or offline mode and also in active or passive mode.
2. To undertake a feasibility study on Lamb wave propagation over undamaged and damaged pipes via smart PZT sensors.
3. To validate the module by modelling the Lamb wave generation and sensing for application on crack identification of pipeline structures.

1.4 Research Scope and Limitation

The research work focuses on the development of wireless SHM system and use of smart PZT sensors of a circular disc type (produced by APC International, USA) which are bonded on the desired pipes. The bonded sensors act as an actuator, and are used for interrogating and acts as a receiver for data acquisitioning on undamaged and damaged pipes. A post analysis of the data was carried out using the MakerPlot software.

The research covers an analytical analysis of the signal from coupon sizes to the actual pipelines. The interpretation algorithm incorporating a wavelet analysis is carried out by the MakerPlot software to analyse the Lamb wave generated from transmitter using Arduino via PZT sensors. Both time and frequency domains were analysed to identify the condition of the structures' features.

Finally, the results of the expirement were compared against the Finite Element Analysis model by using the Abaqus software.

1.5 Organisation of the thesis

The overall thesis covers the development of one of the wireless SHM tools in order to evaluate the undamaged and damaged parts, as the tool is able to change the reliability of the component strength. The thesis is organised in the following manner.

Chapter 2: Literature Review
This chapter presents the background of the research which is divided into three main sections. The first section depicts the application of Structural Health Monitoring system in today's pipelines structures, and challenges of the current damage assessment through various NDTs. The second section presents the sensor technology for the SHM approach. The final section describes the Lamb wave analysis approach using PZT sensors.

Chapter 3: Methodology
This chapter highlights the methodology used in implementing the experiment. Detailed information will be provided on the materials, the apparatus, the software and the programming that were used.

Chapter 4: Results and Discussions
This chapter examines the results obtained by applying the PZT sensors on pipelines parts. A MakerPlot software is used to identify the studied conditions. It also provides indications which can act as the seeding research for future endeavours in this area.

Chapter 5: Conclusion and Recommendations
The final overview of the thesis findings provides a comprehensive conclusion in which all the steps taken in preparing this thesis are aligned with the problem statement and objectives.

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PUBLICATION

Journal

A.A.H.S. Shirazi, F. Mustapha, K.A. Ahmad. (2017) Damage Identification Using Wireless Structural Health Monitoring System Through Smart Sensor Application. International Journal of Advanced and Applied Sciences, 4(2): 38-43

A. H. S. Shirazi, M. K. H. Muda, M. J. Thirumurthy and F. Mustapha. (2017) Wireless Structural Health Monitoring (SHM) System For Damage Detection Using Ultrasonic Guided Waveform Response. Pertanika J. Sci. & Technol. 25 (1): 283 - 292

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