MODELLING OF PIEZO-STRUCTURE ELASTODYNAMIC INTERACTION THROUGH BOND LAYER FOR ELECTRO-MECHANICAL IMPEDANCE TECHNIQUE

by

SUMEDHA MOHARANA

Department of Civil Engineering

Submitted
in fulfillment of the requirements of the degree of

Doctor of Philosophy

to the

Indian Institute of Technology Delhi

November 2012

CERTIFICATE

This is to certify that the thesis entitled, "**MODELLING OF PIEZO-STRUCTURE ELASTODYNAMIC INTERACTION THROUGH BOND LAYER FOR ELECTRO-MECHANICAL IMPEDANCE TECHNIQUE**" submitted by **Ms. Sumedha Moharana** to Indian Institute of Technology Delhi, for the award of the degree of the **Doctor of Philosophy** is a record of bonafide research work carried out by her. She worked under my supervision for the submission of this thesis, which to the best of my knowledge, has reached the requisite standard.

The research reports and the results presented in this thesis have not been submitted in parts or in full to any other University or Institute for the award of any degree or diploma.

Dr. Suresh Bhalla

Associate Professor

Department of Civil Engineering

Indian Institute of Technology, Delhi

New Delhi – 110016

INDIA

ACKNOWLEDGEMENTS

First and foremost, I would like to extend my sincere thanks and gratitude towards my supervisor, Dr Suresh Bhalla, for his continuous guidance, encouragement and strong support during the course of my Ph.D. research. It has been an honour to be associated with Dr. Suresh Bhalla whose suggestions and critical views have greatly helped me in this work. I am eternally grateful for his kindness, helpful guidance, and discussions. He truly exemplifies the role of advisors. I am forever grateful for his kindness and contributions, not only towards my research, but towards my professional growth as well.

I am grateful to my committee members of Prof K. G. Sharma, Dr. Swadesh De and Dr Vasant Matsagar, who provided their useful suggestions and advice regarding my research work. I thank my friends Sanjay and Usha, without them, things would have been very difficult. I am also thankful to my colleague, Vishalakshi, Naveet and Dinesh, for providing imminent helps to conduct the lab experiments.

My thanks are also due to all the Civil Engineering faculty and other staff members for their support and keenness in my work. I am extremely grateful to the staff of Smart Structures and Dynamics Laboratory (SSDL), departmental and central library for providing books, journals etc., which made this research work possible.

I express my special thanks to Mr Lal Singh, Mr Vinod, Mr Mansukh and other technicians, who provided their technical support generously during the lab work. Special thanks go to almighty God and my parent and sisters for their encouragement and love. Their support and kind encouragements provided the essential foundation to thrive and success.

Sumedha Moharana

ABSTRACT

As impedance transducers, the piezoelectric ceramic (PZT) patches have emerged as strong candidates for structural health monitoring (SHM) of structures in the recent years because of their small size and shape, cost-effectiveness and ease of installation. The research for structural identification and long-term monitoring has recently become an area of interest for a large number of academic and commercial laboratories. The associated techniques aim to enable structures and equipment monitor their own structural integrity while in operation, and shall be useful not only to improve reliability, but also to reduce maintenance and inspection costs.

This thesis is focused on the electro-mechanical impedance (EMI) technique for SHM. The basic principle behind this technique is to use high frequencies (typically >50 kHz) generated by surface-bonded PZT patch to detect changes in structural drive point impedance caused by internal/ surface cracks, loose connections, delaminations or any other type of damage. The resultant electro-mechanical interaction, which is characteristic of the particular structure, modulates the current flowing through the PZT patch. The modulation is a function of the mechanical interaction between the PZT patch and the structure over the considered frequency range. The resultant admittance signature, which acts like a frequency response function (FRF), is used to detect changes or damages occurring in the host structure.

The bond layer between the PZT patch and host structure plays a significant role in PZT-structure interaction in the EMI technique. To understand the mechanism of force transfer through the adhesive medium (which introduce shear lag effect) more precisely, various models have been proposed by researchers in the past. Some of those are based on static, dynamic, effective and simplified interaction through the bond layer. However, these models still lack

rigour in terms of considering all governing parameters, especially both shear and inertia terms simultaneously. Understanding shear mechanism phenomena of the adhesive layer is vital for enhanced applicability of the EMI technique.

The main objective of this research work is to model the shear lag phenomena (between PZT patch and host structure) analytically, achieving more accurate model. The previous analytical models have ignored the inertia term, which has been rigorously integrated in this research to arrive at a new refined shear lag model. The new model considers both shear lag and inertia effects simultaneously. The predictions of the new model are much better match with experimental observations as compared to the previous models. Various parametric studies have also been carried out to study the influence of the piezo and the structural properties on the admittance signatures.

The research is further extended by considering the inertia effect of the adhesive mass (so far neglected) in addition to that of the PZT patch. A continuum based admittance approach has been formulated where the "equivalent and effective impedance" terms are replaced by continuum displacement term developed at interfacial adhesive bond. This model considers the bond layer's connection between the patch and structure throughout the sensor length, unlike the previous models which were restricted to boundary interactions. Parametric studies have followed to support the sustainability and suitability of proposed continuum approach. Finally, to enhance the efficiency of the proposed model in real life application on SHM and active control system, the study of electrical power consumption and energy efficiency has been carried out. Various energy conversion efficiency ratios have been obtained by evaluating the total energy used for mechanical response to the total energy supplied. In overall, the study shows significant influence of the bond layer on energy efficiency. A modified electro-mechanical coupling coefficient has been derived from basic strain energy relationship taking care of the mechanical, dielectric and shear lag losses of piezo active control system.

In overall, it is hoped that the outcome of this research will be of significant help SHM based on EMI technique.

CONTENTS