MUCeT
2011
Malaysian Technical Universities International Conference on Engineering & Technology
PROCEEDINGS OF
Malaysian Technical Universities
International Conference on
ENGINEERING AND TECHNOLOGY
"Globalising Innovation for Sustainable Transformation"
13-15 November 2011 | 8.00a.m - 5.30p.m | Katerina Hotel Batu Pahat Johor
Organised by:
UTHM
Universiti Tun Hussein Onn Malaysia
In Collaboration with:
UniMAP
UMP
Universiti Malaysia PAHANG

Overview of Knowledge Retrieval in Cloud Computing	Noryusliza Abdullah, Rosziati Ibrahim
The Effect of TOR as a compatibilizer on Thermal Analysis and Fatique	Dr. Nik Nuriman Zukepli
The Effect of Silane Coupling Agent On Mechanical Properties of Coconut	Koay Seong Chun
The Effect of Silane Coupling Agent on Properties of Coconut Shell	Marliza Binti Mostapha@Zakaria
Development of Universal Motorcycle Basket Shield-A Strong shield for Theft Prevention and Safety	Teh Jenn Hooi, shahriman A.B, Khairunizam WAN, siti Khadijah ZA'BA, Muhammad Khairul A.H, Abdul Halim I, Mohd Nasir A, M Safwan M.A
Influence Of Treatment Time On The Corrosion Resistance Of AZ91D Mg alloy By Chemical Conversion Coating	M.Z.M.Zain, N.F.W.M. Sidik, M. N.B. Derman S.Norbahiyah,S.Illias,N.A.Shuaib
Characterization And Corrosion Studies Of Lanthanum-Based Anodic Oxidation Coating On Mg alloy	M.Z.M.Zain, N.F.W.M. Sidik, M. N. B. Derman, Ismail K.A,M.Mat Salleh,H.Azmi
A Comparison Study on relationship Between Welding Current and Penetration for Plasma Enhanced Shielded Metal Arc Welding (PESMAW)	Dr. S. Thiru Chitrambalam (FKM)
Experimental Investigation on the Effect of Liquid Fill Level in a Container to Liquid Sloshing	Mohd Irwan Mohd Azmi
Component Design of a single Seat Educational Race Vehicle	Fudhail Abdul Munir
Design of a Stand-alone Solar Photovoltic Powered Bus Stop	Mohd Afzanizam Mohd Rosli
A Study of Fin Thickness and Overall Surface Efficiency of Automotive Thermoelectric Power Generator's Heat Sink – A Theoretical Study	Mohamad Firdaus Sukri
Automatic Water Re-Filling	Ahmad Yusairi Bani Hashim (FKP)
Bluetooth Controlled Stairs Climbing Robot	Syamimi Shamsudin
Impact Properties of Epoxidized Natural Rubber / Alumina Nanoparticle Composite (ENRAN)	Dr. Noraiham Mohamad
Preparation and Characterisation of Activated Carbons form Agricultural Waste Rubber Wood Sawdust Through Three Stages Chemical Activation at Low Activation Temperature and Short Retention T ime	Dr. Azizah Shaaban
Finite Element Analysis of Plate Structure Excited by Patches of Piezoelectric Actuators	Mohd Najib Ali Mokhtar
Simulation of Spline Based NC-Manufacturing of Plastic Optical Components	Nik Syahrim Nik Anwar
Fluid Flow Analysis Of Portables Furnace Using Liquid Petroleum Gas (LPG)	Cik Anuar Mohamed Yunus
Characteristics Of Welded Thin sheet AZ31 Magnesium Alloy	Dr Mahadzir Ishak
Wall Driven Flow Simulation Inside Two Dimensional Inverted L-Shape Cavity	Idris Bin Mat Sahat
Review On Biomechanics: A Potential Research	Ir. Ahmad Rasdan Ismail
Effect On Compression Ration On Performance Of Combined Cycle Gas Turbine	Thamir K. Ibrahim
A Quarter Car Active Suspension System Using State Feedback Controller	Dr Gigih Priyandoko
Wind Potential At East Coast Malaysia: Preliminary Study At Pekan	Kumaran Kadirgama
Development Of Virgin Coconut Oil (VCO) Filtration System For Small Scale Industry	Amir Bin Abdul Razak
Fiberglass Reinforced Polymer Composite : An Alternative for Domestic Window Panel	M.I. Idris, H. Taib and M. Zulkipli
Dielectric Modeling of *Rhyzopertha dominica* (F.) For Microwave Heat to the Malaysian Paddy	M.Manjur Ahmed, Fareq Malek, E.M Cheng, R.B Ahmad, Mostafijur Rahman
Effect of Discharge Electrode Pattern to Ozone Production	Noor Ashikin Binti Mohd Razali
Observer Based Sensor Fault Tolerant For Temperature Control System	Ernie binti Che Mid
Optimal Allocation of Embedded Generation in Distribution System Utilizing Artificial Bee Colony Algorithm	Mohd Herwan Bin Sulaiman
Dielectric Properties of $SIO^2$and Best Thin Film	Nur Syakimah Ismail
Design and Analysis of MEMS Based Micro pumps for Medical Application	Norhayati Sabani
The Optical Absorption Spectrum of MEH-PPV Films Below CLA Region	Nurjuliana Juhari
A Real Time Hand Tracking for virtual Object Manipulation	Azri A. Aziz, Khairunizam Wan,Shahriman AB, Siti Khadijah ZA'BA, Abdul Halim Ismail, M.K Ali Hassan, M.Nasir Ayob
TS-7800 Embedded System based Hypo-Vigilance Detection using EEG Channels	Mousa Kadhim Wali, Dr.M.Murugappan, Assoc.Prof Dr.R.Badlishah Ahmad, Mr.Md Mostafijur Rahman
Flexible Antenna using Conductive Textiles	Nurul Husna Mohd Rais, Dr.Mohd.Fareq Malek, Mr Soh Ping Jack
Real-Time Object Detection using Single Board Computer	Nur Farhan Kahar, Mr. Muhammad Syahmi Zainuddin, Assoc Prof Dr R. Badlishah Ahmad
Effect of Reflective Objects of Different Colors to the Output Voltage-Distance Characteristics of Sharp GP2D120 IR Sensor	Mohd Rusdy yaacob
Shape-Based Matching : Application of Defect Detection	Mohamad Haniff bin Harun
Mobile Balancing Robot with Two Heels	Mazree Ibrahim
Modeling of 132kv Overhead Transmission Lines by Using ATP/EMTP for Back-Flashover Pattern Recognition	Nur Zawani Saharudin
Controlling Mobile Robot Via Personal Digital Assistance (PDA)	Ridza Azri Ramlee
The Effect of Electromagnetic Wave of Different Frequencies on Human Skin Cell Using Finite Difference Time Domain (FDTD) Approaches	Mohd Muzafar Ismail
Face Detection Using Probabilistic Neural Network	Khairul Azha A.Aziz (FTK)
ARX Model of Four Types Heat Exchanger Identification	En Tatang Mulyana
Biometric Technique for Future WiMAX Technology	Mohammad Faiz Liew Abdullah
Campus Traffic Light Control System using PIC18F4550 Microcontroller	Hairulazwan Hashim, Jiwa Abdullah and Lee Boon Yong
Controlling Home Appliances Via GSM	A. Amran Mohd Zaid , Khairul Hafiz Abd Wahab and Dirman Hanafi
Harmonic Components Suppression Using Active Power Filter	Asmarashid Ponniran, Mohd Aidil Azhar Shahidi, Ariffuddin Joret
MATLAB Implementation on Hybrid Multilayered Perception Neural Network	Ariffuddin Joret, Nor Ashidi

PROCEEDINGS OF
MALAYSIAN TECHNICAL UNIVERSITIES INTERNATIONAL CONFERENCE ON ENGINEERING AND TECHNOLOGY

Finite Element Analysis of Plate Structure Excited by Patches of Piezoelectric Actuators

Mohd Najib Ali Mokhtar[1], Fairul Azni Jafar[1]
[1]Faculty of Manufacturing, UTEM

Email: najibali@utem.edu.my

Abstract

Active damping using piezoelectric element is one of the effective technique to counter vibration problems. A 3D finite element model is developed as part of investigation for active damping control. The piezoelectric are surface bonded with quadrilateral thin plate and supported with spring damper elements. This simulation project focuses on analysis of the piezoelectric actuators to achieve active damping on plate structure at low frequency spectrum. By numerical simulation the effect of the system in actuator mode at appropriate electric excitation from piezoelectric actuator are investigated. The force induced by piezoelectric actuator under certain applied voltage fields is used as load. Natural frequency of the system and corresponding mode shape are presented and the double symmetric mode shapes are examined. The result can be used as reference or validation of optimal locations and configuration of the piezoelectric patches for active damping control system.

Keywords: Finite Element, Active damping, Plate structure, Piezoelectric transducer.

1. INTRODUCTION

In many machinery and vehicle applications, vibration is unwanted and it can be controlled by creating a design that able to absorb structural vibration energy. Controlling vibration through passive absorbers is a continuous effort but it is usually designed for specific behavior and do not allow flexible adjustment of the parameter in order to achieve comfort and stability of operating conditions [1]. The conception of active vibration control systems was proposed over half a century ago but recent advantages in computer technology made it a practical solution to develop and analyze a system with the help of finite element software before full scale system of vibration control system is developed [2][3][4].

This study presents finite element analysis for thin plate structure excited by patch of piezoelectric transducer. FEM model is created to get the necessary knowledge of optimal location and configuration of piezoelectric actuators in the system at different frequencies. This is first step to develop active damping controlled system using offline approach.

2. FEM SYSTEM SIMULATION

Simulation model consists of 200 mm x 200 mm rectangular steel plate of 0.5 mm thickness supported by polymer structure mounted on rectangular steel base plate. There are two piezoelectric patches of thickness 0. 4 mm bonded on the top side of the plate with a 0.2 mm of adhesive layer.

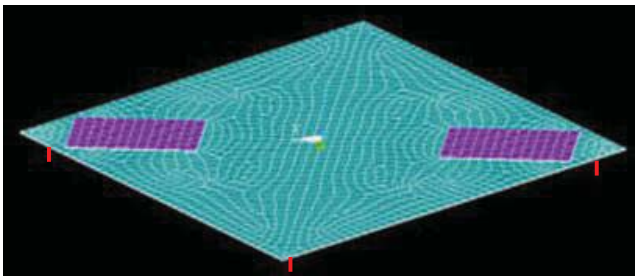

Fig 1: Simulation Model using ANSYS 12.1

[Fig. 1] shows 3D simulation model built in ANSYS 12.1. In the simulation, a 3-D element 'SOLED45' with 3 degree of freedom and 8 nodes is used for modeling the plate structure and bonding layer. A 3-dimensional coupled field element 'SOLED5' with 8 nodes is used for modeling piezoelectric actuators. This element allows coupled DOF of displacement and voltage. The mass of mounting parts of the vibration motor and the sensors are considered as constant value acting at one node and it is represented by structural point mass element 'MASS 21' with 3 degree of freedom (Ux,Uy,Uz). The supports of the plate are modeled by combination element 'COMBIN14' with a DOF in longitudinal Uz direction and have 2 nodes. The constant value of spring constant and damping ratio are defined. The base plate and the air are not to be modeled.

In this study, a quarter model is built for the analysis which means only the symmetry excitation are considered. Examples of symmetry excitation are the force excitation applied in the middle of the plate and voltage excitation applied on the piezo patch which is plane symmetry.

The analysis involved coupled electric-structural problem. The structural problem takes into account the vibration caused by energy transmitted from the piezoelectic patches. The electrical problem is caused by strong coupling effect between mechanical and electrical quantities. For the analysis, DOF's displacement (Ux,Uy,Uz) for structural problem and volt(V) for electrical problem are used.

The behaviors of piezoelectric patches are studied by performing static analysis. The natural frequencies and the mode shapes of the plate structure are identified using modal analysis. Mode shape determines shape of vibration at particular natural frequencies. The overall vibration shape of a structure at finite frequency predominantly determine by it nearest natural frequency of a mode. Therefore modal analysis can be used to validate the selected piezoelement configuration. If all deflection shape is in the domain of influence of piezoelement, then the positions of piezoelements are validated. The area of influence of piezoelements on the structure can be identified using static analysis.

3. MATERIAL DATA AND EQUATION

The following equation describes the behavior of coupled electromechanical problem in the analysis. The value of stress and electric displacement depends on the stress and the electric field quantity in the system.

$$\{T\} = [C^E]\{S\} - [e]\{E\} \quad (1)$$
$$\{D\} = [e]^t\{S\} + [\varepsilon^s]\{E\} \quad (2)$$

Where

$\{T\}$ = Stress vector (six components x, y, z, xy, yz, xz)
$\{S\}$ = Strain vector (six components x, y, z, xy, yz, xz)
$\{D\}$ = Electric displacement vector (x, y, z)
$\{E\}$ = Electric field vector (three components x, y, z)
$[C^E]$ = Stiffness matrix evaluated at constant electric field
$[e]$ = Piezoelectric matrix related to stress over electric field.
$[e]^t$ = Piezoelectric matrix relating stress/electric field (transposed).
$[\varepsilon^s]$ = Dielectric matrix evaluated at constant strain,

For piezoelectric element there are four important parameters describing the physical behavior which are given by manufacturer's data. There are density, relative permittivity, piezoelectric matrix and stiffness matrix.

The piezoelement used for experiment and simulation is PIC252. The material coefficients for PIC252 are the same with PIC255. From manufacturer's supplied data, the coefficient given need to be converted because ANSYS only accepted a certain form of input [5]. Only certain coefficient from the manufacturer's data will be used. The manufacturer's data and the needed data for ANSYS are presented below [6].

In ANSYS input form for stiffness matrix is:

Stiffness Matrix c
[Gpa] :

$$\begin{pmatrix} 123.00 & 76.70 & 70.25 & 0 & 0 & 0 \\ 0 & 123.00 & 70.25 & 0 & 0 & 0 \\ 0 & 0 & 97.11 & 0 & 0 & 0 \\ 0 & 0 & 0 & 23.11 & 0 & 0 \\ 0 & 0 & 0 & 0 & 22.26 & 0 \\ 0 & 0 & 0 & 0 & 0 & 22.26 \end{pmatrix}$$

Manufacturer's data for stiffness matrix are :

$$c11E = 123.00\ \text{GPa}$$
$$c12E = 76.7\ \text{GPa}$$
$$c13E = 70.25\ \text{GPa}$$
$$c33E = 97.11\ \text{GPa}$$
$$c44E = 22.26\ \text{GPa}$$
$$c66E = 23.15\ \text{GPa}$$

The symbol 'E' simply means the stiffness matrix was measured under constant electric field.

ANSYS input form for permittivity matrix:

$$\text{Permittivity Matrix: } \begin{pmatrix} 930 & 0 & 0 \\ 0 & 930 & 0 \\ 0 & 0 & 857 \end{pmatrix}$$

Manufacturer's data for permittivity matrix are:

$$\varepsilon 11Sr = 930$$
$$\varepsilon 33Sr = 857$$

Symbol 'Sr' means permittivity is measured at constant strain.

ANSYS input form for Piezoelectric matrix is:

$$\text{Piezoelectric Matrix}, e^t \left[\frac{C}{m^2}\right]: \begin{pmatrix} 0 & 0 & -7.15 \\ 0 & 0 & -7.15 \\ 0 & 0 & 13.7 \\ 0 & 0 & 0 \\ 0 & 11.9 & 0 \\ 11.9 & 0 & 0 \end{pmatrix}$$

Manufacturer's data for piezoelectric matrix are:

$$e31 = -7.15 \text{ N/Vm}$$
$$e33 = 13.7 \text{ N/Vm}$$
$$e15 = 11.9 \text{ N/Vm}$$

Unit [N/Vm] can be converted to [C/m²] and it will not affect the magnitude.

The density from manufacturer's data needs no conversion. Piezo ceramics density s given as $\rho = 7800 \text{ kg/m}^3$.

Table 3-1: Material properties for Steel Material and Hysol Bond

Physical Properties	Steel plate	Glue (Hysol Bond)
E-Modulus (x 10^9 N/m²)	210	1.7
Density (kg/m³)	8030	3261
Poisson's ratio	0.31	0.34

For a linear elastic calculation in ANSYS, E-modulus, density and Poisson's ratio of the steel plate and glue are needed. The data are presented in Table 3-1.

4. RESULTS

Results of static analysis and modal analysis are presented. The static analysis is used to study behavior of system when voltage is applied as load on the piezoelectric elements.

The results from modal analysis represent all possible mode shape and natural frequencies of the structure. For validation of modal analysis in simulation, experimental analysis using sand was conducted. The sand is put on the plate and excited at different frequencies.

4.1 Static Analysis

To know the general behavior of piezoelectric element and how it will affect the system, static analysis is used. The static analysis is used to calculate the value of maximum deformation of the plate at different voltage excitations. The following figure shows the result of the static analysis at voltage excitation of 50 volts. At first 50 volts is applied at upper layer and the lower layer of piezoelement is set to 0 volts. For the second analysis, upper layer is set to -50 volts.

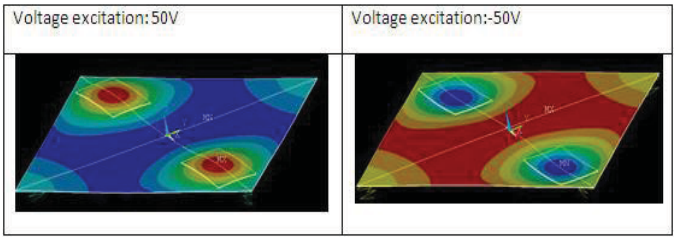

Fig 2: Static analysis at different voltage excitations

At positive voltage [Fig 2: The left figure], the piezoelectric expands laterally. Since patch is bonded to the plate, it produced extension at the upper plate and compression at lower plate. The application of an electric field along the polarization direction make the patch expand in the perpendicular direction, thus producing a local strain on the patch and bend the plate upwards. Local maximum occur at area where the piezoelectric patch are bonded with the plate. It occurred at around the centre of the patch actuator at node 21416 and node 21417.

At negative voltage [Fig.2: The right figure], there is contraction at piezoelectric actuator and it worked vice versa. The application of electric field opposite to the polarization direction make the piezo actuator contract in the direction perpendicular to the electric field and bend the plate downward.

4.2 Natural Frequency and mode shapes

The method of extraction of the mode shape using ANSYS is modal analysis. The analysis will investigate natural frequencies and mode shapes of all possible excitations. For the analysis, frequency spectrum from zero to 500 Hertz is selected and the analysis results are presented. The mode shapes are then compared with experimental results. The experiments are conducted using sand which is placed on the vibration plate. The system is then excited at particular frequency and the shape of the sand after certain time is captured using camera.

The five first natural frequencies and its corresponding mode shapes are found and Fig.3-Fig.7 illustrated the natural frequencies of the system and the corresponding mode shapes during simulation and experimental results used to validate the results.

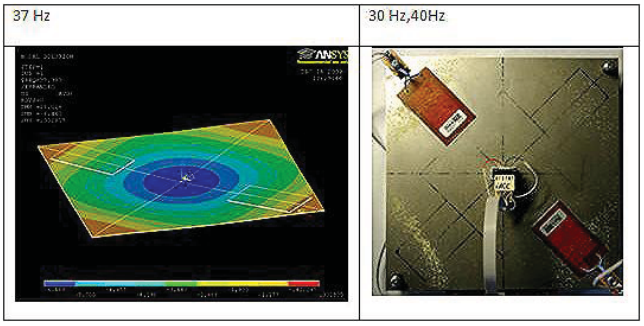

Fig 3: First mode shape from simulation and experiment

The system is excited using piezo patch with voltage excitation of 50V. The colours represent the magnitude in term of displacement. Red colour represents maximum position, blue colour represents minimum position and the green colour is the neutral position which is equivalent to no displacement. [Fig. 3] on the left side shows the first mode shape from both the simulation and experimental analysis. The right figure shows the shape of the sand recorded at 30Hz and 40Hz. At 37 Hz natural frequency occur and the corresponding figure shows that the centre of the plate moves downward whereas the four edges are in phase and move upward. As one can see, the green line has the shape with the sand form on the plate.

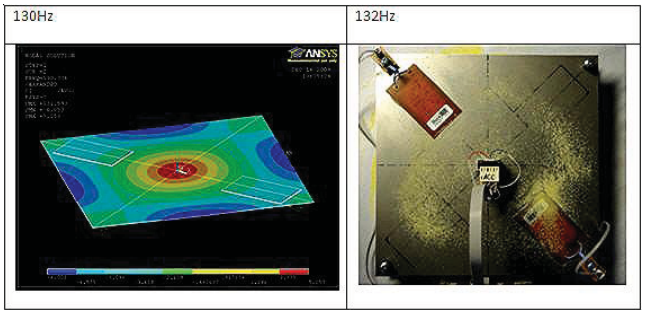

Fig 4: Mode shape at second natural frequency

[Fig. 4] illustrates the mode shape resulting from the force excitation from the vibration motor.
At second natural frequency, the centre plate moves to maximum point. All four side edges near tend to deform in upwards direction in phase. From simulation the second natural frequency of the system is found at 130Hz. The neutral line is a circle touching the upper side of the piezo patch. The sand form which are excited at frequency 132Hz also have the similar shape and therefore validate the mode shape.

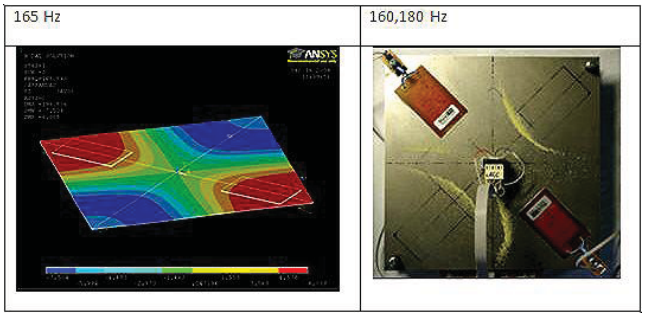

Fig 5: Third natural frequency of the system

The third natural frequency is found when the piezo patch is supplied with 50V at frequency 165Hz. The sand form in [Fig. 5] which are excited at frequency 160Hz and 180Hz have similar shape with resulting neutral line from simulation analysis. The mode shape shows that edges at piezo patch side move to minimum point whereas the other two sides move to maximum points. No displacement line which is illustrated by green colour and sand form has a cross shape.

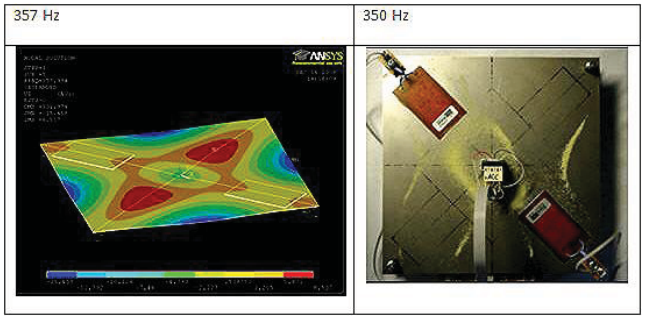

Fig 6: Forth natural frequency of the system

[Fig. 6] shows the forth natural frequency is found when the piezo patch is supplied with 50V at frequency 357Hz. On the right figure shows similar shape resulted from the experiment at exciting frequency of 350Hz. The mode shape shows that there are neutral line existed at sides of the plate and at the centre where the sensor are placed.

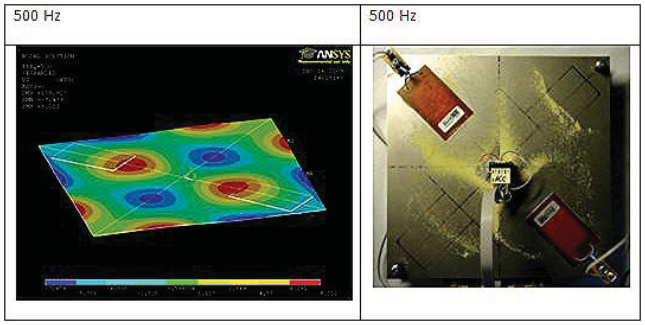

Fig 7: Mode shape at frequency of 500 Hz

[Fig. 7] shows mode shape from simulation in ANSYS and experiment at exciting frequency of 500Hz. The nearest natural frequency of similar shape is 404 Hz resulted from modal analysis. The similar

form resulted from the experiments validate the mode shape from simulation.

6. CONCLUSION

The results of static analysis reveal a general behavior of piezoelectric system when electrical excitation is applied. It is useful to understand the shape when load is applied and calculate the deformation of system regardless of frequency of excitation.

In the second analysis, the system operational frequencies are considered and using finite element software, modal analysis is conducted and results of all possible mode shape and natural frequencies of the structure at low frequency range are presented. The results which presented at Figure 3-7 show that the neutral displacement line was in the region of selected position of piezoelectric membrane and therefore verify the effective position to suppress the vibration at lower frequency range.

From the results it shows that experimental approach to determine mode shape at selected frequency agreed with results from simulation and therefore can be used for future study of offline identification approach in order to determine the transfer function of system, and hence development of classical PID controller for the system can be done. The controller can be used in active damping to control the noise vibration of the system.

ACKNOWLEDGMENT

The simulation and experiments was part of engineering project during study in Aachen University, Germany. The authors thank for the financial support from University Technical Malaysia Malacca throughout the study. Special gratitude to my supervisor Prof. Dr. Klaus-Peter Kämper and Prof.Dr.-Ing.Hans-Jürgen Raatchen. I am also very thankful to Oliver Pütsch, Mr.Ashkan Davanlao and Faisyal Sarifuddin.

REFERENCES

[1] Teixera,R.L., Lepore Neto, “Modeling and experimental investigation of an active damper”, Shock and Vibration, ISSN 1070-926/06-IOS Press, 2005.
[2] H. Karagülle,L Malgaca,H F Öktem, “Analysis of active vibration control in smart structures by ANSYS”, Institute of Physics, 2004.
[3] Mohammed W. Al Hazmi,“Finite Element Analysis of cantilever structure excited by patches of piezoelectric actuators”, IEEE, 2008.
[4] M.S. Kozien, B. Koltowski,”Comparison of active and passive damping of plate vibration by piezoelectric actuators-FEM Simulaton”, Acoustic and Biomedical Engineering, Vol. 119 , 2011.
[5] ANSYS software manual, ANSYS 12.0, ANSYS inc.
[6] Piezoceramic material data PIC 255, Physik Instuments GmbH & Co.