NUMERICAL SIMULATION OF SOUND ABSORPTION COEFFICIENT OF WOOD PERFORATED WALL PANEL WITH UNIFORM SMALL GEOMETRIC PATTERNS

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Dedicated to my beloved husband,Mohd Muzaffar bin Zahar,

and also to my beloved family, especially my mother; Che' Mazenah binti Gah,

my father; Hassan bin Ab Ghani, my siblings, who have encouraged, guided and

inspired me throughout my journey of education.

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ABSTRACT

Wood perforated wall panel with geometric pattern is a form of direct piercing carved wood panel (DPCWP). It has been extensively used as decoration element in Malay architecture especially in palaces, mosques, public building and some houses. The important aspect focused on this DPCWP is its ability to act as sound absorber. The sound absorption coefficient (SAC) α_n, of wood perforated wall panel with uniform and small geometric patterns at 1kHz to 4kHz frequency band shall be improved optimally through the contribution of perforation ratio and resonance frequencies. From previous findings, the hypothesis is that wood perforated wall panel with uniform small geometric patterns gives good sound absorption performance at 1kHz to 4kHz frequency region. Two patterns of DPCWP are designed using resonance frequency technique at 1/3 octave centre frequency from 1.6kHz to 5kHz with perforation ratio in the range of 35% to 40% and have been successfully investigated. Simulation process is carried out using BEASY acoustics software, which is an established numerical modelling tool for Boundary Element Method (BEM) works. Numerical modelling based on BEM has been widely used for engineering design and prediction. Results show that it has almost the same trend with those in previous results. However, at frequency 1kHz to 4kHz, α_n results show an increment to the higher α_n compared to the previous results which are show small α_n values at the same frequencies. The higher α_n phenomena at high frequencies shown by the best samples, S5 and S7 are due to resonance frequency inside the air column in DPCWP apertures. Noise reduction coefficients (NRC) calculated in the region of 0.75 to 0.95 prove that DPCWP with uniform and small geometric pattern able to act as good sound absorber. This finding allows DPCWP to be used as sound absorber more effectively mosques and other enclosed rooms.

ABSTRAK

Panel dinding kayu bertebuk dengan corak geometri adalah salah satu bentuk panel ukiran kayu bertebuk terus (DPCWP) yang telah digunakan secara meluas sebagai elemen hiasan dalam seni bina Melayu terutama di istana, masjid-masjid, bangunan awam dan rumah-rumah. Aspek penting yang telah ditumpukan kepada DPCWP ini adalah keupayaan untuk bertindak sebagai penyerap bunyi. Pekali penyerapan bunyi (SAC) α_n, bagi panel dinding kayu bertebuk dengan corak geometri kecil seragam pada jalur frekuensi 1kHz hingga 4kHz boleh ditingkatkan secara optimum melalui sumbangan nisbah penembusan dan frekuensi resonan. Daripada hasil penyelidikan yang lepas, ia boleh dihipotesiskan bahawa panel dinding kayu bertebuk dengan corak geometri yang kecil dan seragam mempunyai prestasi penyerapan bunyi yang baik pada jalur frekuensi 1kHz hingga 4kHz. Dua corak DPCWP direka berdasarkan teknik frekuensi resonan pada frekuensi tengah 1/3 jalur oktaf daripada 1.6kHz hingga 5kHz dengan nisbah penembusan dalam lingkungan 35% hingga 40% dan telah berjaya dikaji. Proses simulasi telah dilakukan menggunakan perisian akustik BEASY, perisian pemodelan berangka yang telah digunakan secara meluas bagi kerja-kerja Kaedah Unsur Sempadan (BEM). Permodelan berangka berdasarkan BEM telah digunakan secara meluas untuk reka bentuk kejuruteraan dan ramalan. Hasil penyelidikan menunjukkan keputusan yang hampir sama dengan hasil penyelidikan yang lepas. Namun, pada frekuensi 1kHz hingga 4kHz, nilai α_n telah meningkat kepada nilai yang lebih tinggi berbanding hasil penyelidikan yang lepas di mana nilai α_n adalah rendah pada frekuensi yang sama. Nilai α_n yang lebih tinggi ini ditunjukkan oleh sampel yang terbaik, S5 dan S7 yang menunjukkan bahawa ia berlaku kerana kesan frekuensi resonan di dalam ruangan udara pada bentuk DPCWP. Pekali pengurangan bunyi (NRC) yang dikira dalam lingkungan 0.75 hingga 0.95 membuktikan bahawa DPCWP dengan corak geometri yang seragam dan kecil mampu untuk bertindak sebagai penyerap bunyi yang baik. Penemuan ini membolehkan DPCWP boleh digunakan sebagai penyerap bunyi yang lebih berkesan dalam pembinaan masjid dan ruang tertutup pada masa akan datang.

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LIST OF SYMBOLS

E_i	-	Incidence energy
E_r	-	Reflected energy
E_a	-	Absorbed energy
E_t	-	Transmitted energy
I_i	-	Incident sound intensity
I_r	-	Reflected sound intensity
I_a	-	Absorbed sound intensity
I_t	-	Transmitted sound intensity
I_n	-	Net sound intensity
α_n	-	Sound absorption coefficient
f_s	-	Frequency resonance
W_i	-	Incident sound power
W_r	-	Reflected power
W_a	-	Absorbed power S
W_t	-	Transmitted power
W_n	-	Net sound power in front the material
W	-	Sound power level
A	-	Surface area
n	-	Integer (1,2,3,…)
d	-	Aperture diameter or the longest length
c	-	The speed of sound
σ	-	Perforation ratio
λ	-	Wave length

LIST OF ABBREVIATIONS

BEM	-	Boundary Element Method
DPCWP	-	Direct Piercing Carved Wood Panel
FEM	-	Finite Element Method
NRC	-	Noise Reduction Coefficient
RSIE	-	Resultant sound intensity in an empty anechoic room
RSIP	-	Resultant sound intensity in front of the panel in anechoic room
RT60	-	Reverberation time
SAC	-	Sound Absorption Coefficient
SPL	-	Sound Pressure Level
UTM	-	Universiti Teknologi Malaysia
WCPP	-	Wood Circular Perforated Panel

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CHAPTER 1

INTRODUCTION

1.1 Background of the Problem

Wood perforated wall panel with geometric pattern is a form of direct piercing carved wood panel (DPCWP) which has been extensively used as decoration element in Malay architecture especially in palaces, mosques, public building and some houses. In houses and mosques, wood carving perforated panel has been used mostly as part of the wall panels and also on the upper part partition of the doors and windows. In tropical country like Malaysia, the wood carving perforated wall panel is also used to help in achieving thermal comfort and fresh air circulation in rooms. In addition, the use of wood carving is also for natural lighting during the day. But in early traditional houses, the wood carving especially in the main room serves not only as a decorative element but also reflects the social status of the owner (Lim Jee Yuan, 1987). The important aspect of DPCWP is the ability to act as sound absorber (Lai, 1991; Maekawa and Lord, 1994; Kutruff, 1979; Creamer and Muler, 1982). This is the main issue of this research.

In this thesis, it is envisaged, DPCWP with uniform small geometric pattern shall be a better alternative to earlier investigated DPCWP. This is considering mosque walls design with uniform and small geometric pattern DPCWP shall function better acoustically at 1kHz to 4kHz frequency range. Besides that, this DPCWP can possess unique ability not allowing birds especially to pass through.

1.2 Statement of the Problem

From previous research work was done on DPCWP with geometric patterns shows that sound absorption coefficient, α_n at 250Hz to 500Hz frequency range is very high and almost constant followed by a decay trend at frequency region between 1kHz to 4kHz. While, earlier research work by Munirul Ula (2007) strongly suggest that improvement of α_n at high frequency is mainly due to resonance frequency effect occurred inside the air column in WCPP apertures. Extension to this study, a research work done by Mohamad Ngasri Dimon (2009b) verified that the shifted α_n is foreseen to be caused by difference resonance frequencies which are 1kHz, 2kHz and 4kHz for the respective WCPP designed sample. So that, it is pertinent and important to improve further α_n at high frequency through the contribution of resonance frequencies technique on DPCWP with geometric patterns designs.

1.3 The Objectives of the Research

i. To design uniform and small geometric pattern DPCWP using resonance frequency technique at $1/3$ octave centre frequency from 1.6kHz to 5kHz.

ii. To numerically investigate normal incidence sound absorption coefficient (SAC), α_n characteristics of DPCWP with uniform small geometric patterns set to resonate at 1.6kHz to 5kHz due to $^1/_3$ octave centre frequency.

iii. To analyze the sound absorption performance of DPCWP at 1kHz to 4kHz frequency range based on resonance frequency technique.

1.4 Scope of the Work

The research work involved boundary element method simulation of DPCWP using Beasy Acoustics software. The basic of the samples created are based on previous research by Mohamad Ngasri Dimon (2009a) and the resonance frequency technique used is as suggested in previous research by Munirul Ula (2007) and Mohamad Ngasri Dimon (2009b). Eight DPCWPs are design using resonance frequency technique at $^1/_3$ octave centre frequency from 1.6kHz to 5kHz. The DPCWP samples thickness is 20 mm and the perforation ratio are vary within 35% to 40% depends on the frequency resonate to the design of the panels. Next, α_n results are compared with simulation and experimental results from previous study.

1.5 Significance of the Study

Wood perforated wall panel with uniform small geometric patterns are hypothesized will result in good sound absorption performance at 1kHz to 4kHz frequency range. Therefore, this research on DPCWP with uniform small geometric pattern shall be a better choice to earlier investigated DPCWP. This is considering mosque walls design with uniform and small geometric pattern DPCWP shall function better acoustically and the findings shall allow DPCWP to be used as sound absorber more effectively in future mosques and enclosed room construction. Besides that, this DPCWP can possess unique ability not allowing birds, especially, to pass through.

1.6 Contributions of the Thesis

i. Two patterns of DPCWP which were design using resonance frequency technique at 1/3 octave centre frequency from 1.6kHz to 5kHz with perforation ratio in range of 35% to 40% have been successfully investigated.

ii. Sound absorption coefficient, α_n of all eight DPCWP samples suggest higher α_n as compare to previous DPCWP α_n , where the design was based on random aperture design technique.

1.7 Research Outline

This thesis is divided into five chapters, which describe the entire process of the research. The outline of the thesis is as follows:

Chapter 1 highlights the background of the research problem, statement of the problem and objectives of the research. It follows by research scope, significance of the study, contribution of the thesis and thesis outline.

Chapter 2 overview on the Islamic pattern and followed by discussion on geometric pattern, description on two types of DPCWP with geometric patterns used for this research and examples of perforated panel used in mosque. Then, it continued with the description on the theory of the resonance frequency technique, perforated panel absorber and normal incidence sound absorption coefficient. Next, it followed by the literature review on earlier research works and related research works done by other researchers.

Chapter 3 discusses the details on the research process starting with dimension and calculation for creation of Direct Piercing Carved Wood Panel (DPCWP) due to resonance frequency, followed by the details on designed process using AutoCAD software and continued with the modeling and simulation process using BEASY Acoustic software

Chapter 4 discusses the analysis of sound absorption coefficient, α_n and NRC for each sample and continued with comparison of the results with previous research. Finally, this chapter discusses the significant test for all simulation results.

Chapter 5 concludes the research work and gives the suggestion for future development of the related research project.

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