INVESTIGATION ON THE OPTIMAL CONFIGURATION OF SOUND ABSORPTIVE MATERIAL FOR AUTOMOTIVE APPLICATION

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2022

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THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF BACHELOR OF ENGINEERING WITH HONORS (MECHANICAL ENGINEERING)

FACULTY OF ENGINEERING
UNIVERSITI MALAYSIA SABAH

2022

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DECLARATION

I hereby declare that this final year project, entitled "Investigation on the Optimal Configuration of Sound Absorptive Material for Automotive Application," submitted to Universiti Malaysia Sabah as a partial fulfilment of the requirement for the degree of Bachelor of Mechanical Engineering and has not been submitted to any other university for any degree. I also certify that the work herein entirely my own, except for quotations and summaries sources of which have been fully acknowledged under the supervision of Ir. Ts. Mohd Amran bin Hj Madlan.

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22 JULY 2022

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CERTIFIED BY

IR. TS. MOHD AMRAN BIN HJ MADLAN

SUPERVISOR

ACKNOWLEDGEMENT

First and foremost, thousand praises and thanks to The Almighty God, for His blessing showers throughout all my times and His gift of health and prosperity, I managed to complete my final year project. Throughout these two semesters of final year, I have been heavily blessed with various supports from several figures and people in the process of completing this research.

Million thanks to my supervisor, Ir. Mohd Amran bin Madlan for being a guiding light and constantly giving sheer motivations and advice throughout the duration of Final Year Project (FYP). This research would be impossible without his intuition and trust to accept me as his FYP student. Furthermore, his guidance and teachings are extremely crucial in conducting the research procedures.

My deepest gratitude goes to all my family members especially to my parents, Mr. Haron and Mrs Norliza. Without their endless mental support, understanding and necessary aid from the beginning, it would be possible for me to complete writing this thesis. Also, to all my siblings; Anis Athirah, Anis Afiqah, Anis Aribah, Arif Afzan, Anis Awadah and Anis Alisha, they are the reason why I need to keep striving and show a good example as the eldest brother.

Lastly, I would like to express my gratitude to all my friends, especially to Nor Adiba Farhanah for always sharing fruitful thought and always be my side through ups and down for more than 4 years. To sum up, degree's life is so short yet so meaningful, memories and experiences are shared and gained that helped me to become the best version of me. Also, I would like to thank those who are directly or indirectly involved in this research, you should know that your presence was worth and means a lot to me. Most important, thanks to myself for surviving throughout this degree!

ABSTRACT

In urban cities, public transport such as trains and monorail play an important role as one of the main transports used by workers and students as transportation from one place to another. However, the noise made inside the train by its mechanics frequently disturbs the passengers. Where the train's motor, gearbox, and bogie are located beneath, that is where the noise is coming from. Thus, the main objective of this research is to determine and obtain the optimal configuration of the sound absorptive materials for automotive application focusing in trains/monorail. Three specified objectives were set; which are to design the three different thickness of metamaterials and simulate the behavior towards the sound waves produced; to determine the insertion loss in the train at various frequencies when metamaterials are installed and to analysis the effect of the sound absorbing metamaterial based on the simulation performance. Three types of metamaterials were chosen to be fitted underneath the train; aluminium alloy foam, stainless-steel foam and stainless-steel fiber with 1mm, 3mm and 5mm thickness. The train prototype is done by using SolidWorks software, and the simulation study conducted through COMSOL Multiphysics software. Sound pressure level (SPL) before and after the metamaterials were installed are been collected and discussed to compare and determine the best SPL reduction and highest insertion loss. Aluminium alloy foam with 5mm thickness turned to be the most effective materials to be installed with 16% of SPL reduction. It portrays the highest insertion loss in low frequency range. In addition, all metamaterials with 5mm thickness shows the best sound absorbing materials which is parallel to the relationship with greater thickness of sound absorber materials, will results a greater insertion loss and SPL reduction. To sum up, it is a success study as the overall average SPL in train were reduced from 90.4dB to 76.1dB.

ABSTRAK

SIASATAN TERHADAP KONFIGURASI OPTIMAL BAHAN SERAP BUNYI UNTUK APLIKASI AUTOMOTIF

Di bandar, pengangkutan awam seperti kereta api dan monorel memainkan peranan penting sebagai salah satu pengangkutan utama yang digunakan oleh pekerja dan pelajar dari satu tempat ke satu tempat. Walaubagaimanapun, bunyi bising yang terhasil di dalam kereta api sering mengganggu penumpang. Oleh itu, objektif utama penyelidikan ini adalah untuk menentukan dan mendapatkan konfigurasi optimum bahan penyerap bunyi untuk aplikasi automotif memfokuskan tren/monorel. Tiga objektif utama telah ditetapkan; iaitu untuk merekabentuk tiga ketebalan bahan metamaterial berbeza dan mensimulasikan respon terhadap gelombang bunyi yang terhasil, untuk menentukan nilai kehilangan sisipan dalam kereta api , dan untuk menganalisis kesan bahan metamaterial penyerap bunyi berdasarkan simulasi. Tiga jenis bahan metamaterial telah dipilih untuk dipasang di bawah kereta api; buih aluminium aloi, buih keluli tahan karat dan gentian keluli tahan karat dengan ketebalan 1mm, 3mm dan 5mm. Kajian simulasi dijalankan melalui perisian COMSOL Multiphysics dan tahap tekanan bunyi sebelum dan selepas metamaterial dipasang dibincangkan dan menentukan bahan penyerap bunyi yang terbaik. Buih aluminium aloi dengan ketebalan 5mm menjadi bahan paling berkesan untuk dipasang dengan pengurangan tekanan bunyi sebanyak 16%. Di samping itu, semua bahan metamaterial dengan ketebalan 5mm menunjukkan bahan penyerap bunyi terbaik yang selari dengan hubungan apabila ketebalan bahan penyerap bunyi yang lebih besar, akan menghasilkan kehilangan sisipan dan pengurangan tekanan bunyi yang lebih besar. Ringkasnya, ini adalah satu kajian yang berjaya kerana purata keseluruhan tahap tekanan bunyi dalam kereta api telah dikurangkan daripada 90.4dB kepada 76.1dB.

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dB	Decibels
SPL	Sound Pressure Level
mm	Millimeter

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter provides an overview of the entire research paper. It also contains information about the project's background, problem statement, research objectives, scope of works, research expected outcome, contributions and thesis organization.

1.2 Introduction

Since the first indigenous vehicle, the "PROTON," was produced in 1983, the automotive sector has grown to become one of Malaysia's most important businesses. Malaysia now has around 20 manufacturing and assembly factories that produce passenger cars, commercial vehicles, motorbikes, scooters, and other public transportation vehicles(NAP2020_Booklet, 2020). By years, the automotive applications are demanding and currently is a need for everyone in this country. The usage of environmentally friendly transportation such as a monorail and trains are given high importance nowadays, which is designed to provide connection between one place to another.

A full rail ecosystem is required to sustain the current and newly planned rail transportation systems. Technology and human capital development are two of the key drivers for the Malaysian rail industry's future. Malaysia should take advantage of the growing rail sector by extending its know-how base to support present and future assets, as well as by conducting research and development to discover new rail technology as it will make traveling inside cities and between cities is becoming more convenient, quicker, and cheaper as the network of train and other means of public transportation expands, as well as the advent of new technology. However, as the technologies in automotive develops, some action need to be taken regarding on complaints that related to noise and vibration from the construction or any train/monorail works operations in order to resolve any noise and vibration issues. This includes noise and vibration from passing trains, idling locomotives, shunting and the "stretching" and compression of trains.

Unwanted sound is referred to as noise. For example, one individual may find a specific genre of music relaxing while another finds it irritating. Meanwhile, vibrations produce sound, which is a form of energy. When an item vibrates, it causes the molecules in the air around it to move. These molecules collide with nearby molecules, forcing them to vibrate as well. As a result, they collide with more adjacent air molecules. Sound waves are a "chain reaction" movement that continues until the molecules run out of energy (Science World, 2021).

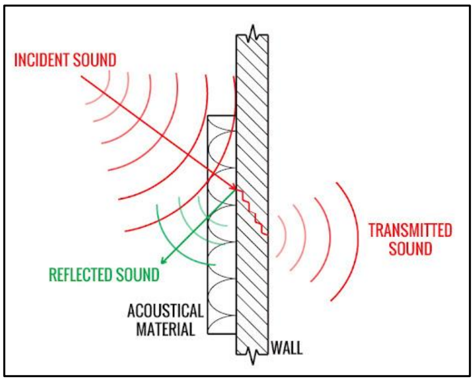

Figure 1.1 Absorb, reflect or transmit sound striking the wall

Source: (Technature Inc., n.d.)

The incident sound that strikes a medium and is not reflected back is characterized as sound absorption as shown in Figure 1.1. When a sound wave hits an acoustical material, it vibrates the fibers or particles that make up the absorbent material. Due to the friction, this vibration generates a little quantity of heat, and therefore sound absorption is achieved through energy to heat conversion (Sound Absorption, 2018). Due to that, acoustic metamaterials (AMM) have garnered a lot of interest in recent years, and they looked to offer up a new way of building acoustic devices. The small size and broad band performance of AMM make it more suitable for practical noise reduction. Moreover, is it an interesting topic to have as the metamaterials have their specific properties, including negative and varying Poisson's ratios, nonlinear force–displacement relationships, bi- or multi-stable states, the ability to absorb vibration energy, negative bulk modulus (Burov et al., 2009), and negative refractive index (Huang & Sun, 2012).

The research aim is to find the most optimal thickness of sound absorptive metamaterial in automotive applications in order to achieve allowable noise level (dB) in trains/monorail. Hence, various simulation with different of these materials are also studied to further demonstrate the actual results of the materials behaviors. Since the investigation will be centered on automotive applications which is trains and monorails, several factors need to be amended such as the dimension, thickness, and the location of material used to be implemented in the trains/monorail. The virtual simulations and mathematic analysis by comparing the noise level before and after implementing the materials and also the insertion loss of the respective materials have been done in order to portray the behavior of each different configurations for the sound absorptive materials.

1.3 Problem Statement

Urbanization and the development of urban rail transit are mutually linked. Urbanization brings with it certain unavoidable problems, such as traffic congestion, air pollution, and land shortage, to name a few. In addition, urban rail transportation, which includes metros, light rail, monorail, and MRT/LRT, is an efficient way to alleviate traffic congestion and pollution. However, as the urban population grows and train infrastructure expands, the distance between urban areas and railway corridors shrinks, raising concerns about railway-induced vibrations (Connolly et al., 2016). Despite the fact that trains in urban areas travel at a slow pace, train-induced vibration can travel from the tracks through the columns and walls into the platform and some more places, where it might affect the inhabitants (Zou et al., 2017). In terms of feelable vibration and noise, train-induced vibration may cause discomfort and annoyance to persons living or working in over-track structures. It can also have a negative impact on the operation of vibration-sensitive equipment used in medical laboratories and high-tech industries. As a result, it's critical to comprehend, forecast, and analyze the impact of train-induced vibration on surrounding building occupants in order to create mitigation strategies if necessary.

Mohd Masirin et al., (2015) stated on previous research of a passenger view on train noise and vibration stated that the highest noise level inside of the MONOREL was during the route from Titiwangsa to Chow Kit with 80.3 dB and a PUTRA LRT from Bangsar to Abdullah Hukum with 87 dB. It is quite a big different with WHO recommended guideline values for average noise exposure to reduce noise levels below 54 dB L_{den} ; day-evening-night-weighted sound pressure level as defined in section 3.6.4 of ISO 1996-1:20161 (WHO, 2018). Both stations located in an urban area hence it has increased the detrimental effects on human health and well-being as it becoming a major source of public concern. It's vital to figure out whether the train's noise and vibration levels are causing substantial pain to the passengers directly or indirectly.

Hence, this study will propose a simulation on three different thickness; 1/3/5 mm of three different types of sound absorptive materials (metamaterials) through a train prototype. The simulation will be applied as in an automotive application for train specifications to determine the most optimal thickness for reducing noise generated in particular trains. The metamaterials that been applied in the body of train is decided to be located underneath of the body and this study will result the outcome of the simulation works.

Thus, in the eyes of the public, this study will demonstrate and generate a better service especially to the passengers and come up with fresh ideas and knowledge to our railway services. This provided a chance to compensate for the flaws and provided a clearer picture of the train services' comfortability.

1.4 Research Objectives

The main objective of this project paper is to determine and obtain the optimal configuration of the sound absorptive materials for automotive application focusing in trains/monorail. The project main objective was specified into three specific objectives as following;

i. To design the three different thickness of metamaterials and simulate the behavior towards the sound waves produced;
ii. To determine the insertion loss in the train at various frequencies when metamaterials are installed;
iii. To analysis the effect of the sound absorbing metamaterial based on the simulation performance.

1.5 Scope of Works

The scope of work for this project paper is organized into the following task:

a. Material Study and Identification

Leads in the identification and selection of materials. The metamaterials are identified based on the literature review and previous application in the industry. The materials with specific properties are chosen considering some aspects such as; the aspects of the arrangement of the materials, the composition of materials and the thickness of material used in the simulation are taken into account in this research to achieve an optimal efficiency of the sound absorption in the system as well as verifying the engineering theories of acoustics used.

b. Design of Simulation Model

Setting up the train model by using SOLIDWORKS based on ISO 20189:2018 and according to the material properties and measurements. Assemble the system's component correctly and ensure the system can functions properly to have an accurate results and graphs plotted.

c. Simulation Analysis

Oversees the overall simulation of the materials applied in the automotive application using COMSOL Multiphysics. It is used in order to determine the sound absorption behavior for each metamaterial in different thickness and figure out the optimal configurations for the implementation in automotive applications especially in trains/monorail.

1.6 Research Methodology

This study was carried out according to a set of methodology that had been planned, as following:

a. Preliminary Literature Review

Any useful previous researches or studies that is relevant to this project where the finding is useful in assisting and carrying the project will be used for reference. This includes the characteristics of the sound absorptive materials, fundamentals of acoustics and any references in terms of acoustic configurations to be taken as comparison to improvise this project paper.

b. Model Simulation Performance Assessment

The performance assessment was conducted from the simulation analysis based on the ISO 20189:2018 using software COMSOL Multiphysics and the results were evaluated afterwards for simulation and result validation.

c. Result Verification and Validation

All the findings of the simulations that have been done are compared to validate the results obtained. Verification and discussion in detailed in order to ensure that the objectives fulfilled.

d. Documentation and Discussion

All the findings from this research and academic references from the literature review were documented and been discussed as a standard project report for future references.

The research project is conducted according to the flowchart shown below

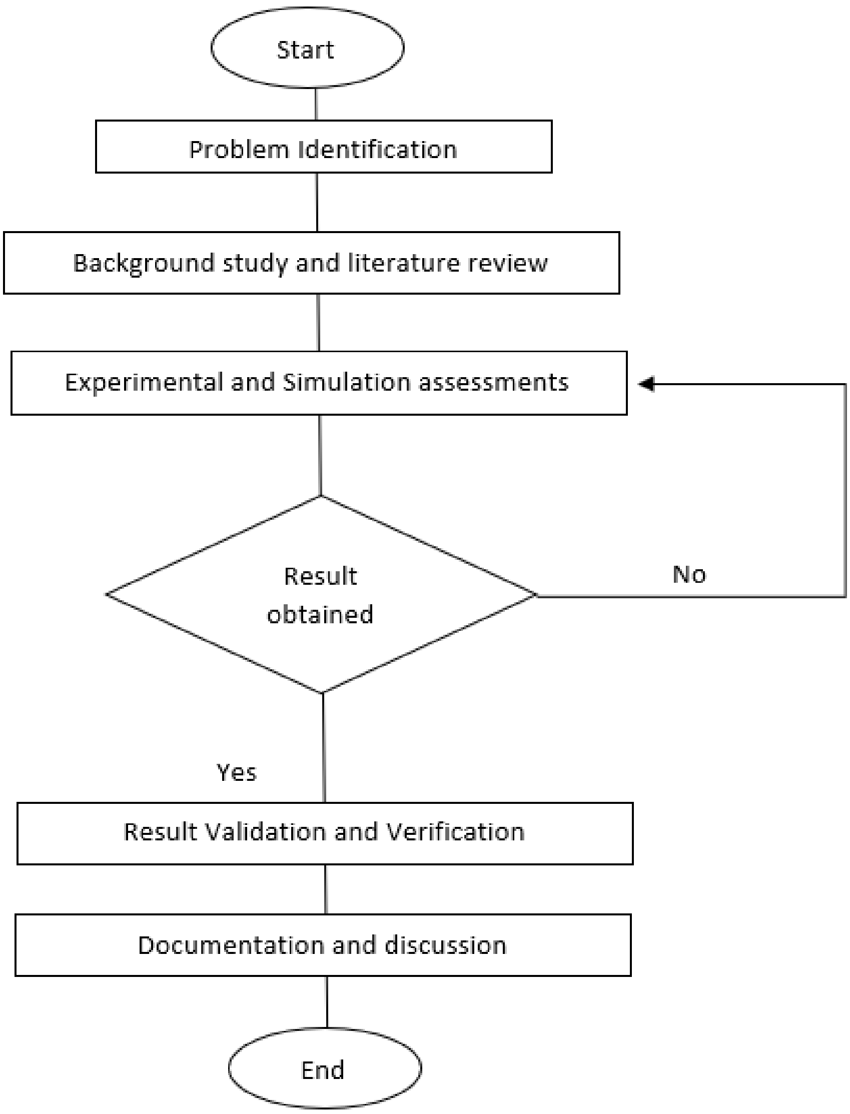

Figure 1.2 Project paper methodology flowchart

1.7 Research Expected Outcome

For this project paper, there are several key outcomes that can be expected from this research. Certain factors including the thickness of the sound absorptive metamaterials, the type of metamaterials used, the location of the sound absorptive metamaterial underneath the body of trains/monorail and the characteristics of the metamaterials relative to the sound waves propagated are crucial in determining the optimal thickness for the sound absorptive material in reducing noises generated from the body or parts in the trains/monorail.

Adjusting parameters such as density and thickness can further improve the sound absorption efficiency of metamaterials. All these factors may thus be utilized to generate a better sound absorber that can efficiently absorb sound at a certain frequency range. This research therefore anticipated a fair comparison of insertion loss through each of these metamaterials.

1.8 Research Contributions

In an automotive industry, it is really important to provide the best services for the clients. Thus, this research of studying the optimal configuration on sound absorptive material for automotive applications expected to contribute in reducing the implications on health impacts especially from transportation noise. This is due to the exposure of public to noise can lead to auditory and nonauditory effects on health. It might cause tinnitus or hearing loss and also a long-term exposure. Overall, this research and knowledge can be used for the development of automotive industry and applications especially in Malaysia as it has not been exposed and developed enough for a next phase yet.

As the optimal thickness of the absorption materials for the trains/monorail is known in terms of acoustic principles, the noise produced from the trains/monorail can be controlled and reduced and come out even with a better and healthier environment to establish a better working environment for industrial workers by minimizing the dangers of acoustical discomfort, which can affect their health. In addition, various technical specialists and decision-makers either at the local, national, and international levels who are responsible for formulating and enforcing noise control legislation and standards, particularly in railways at urban planning and housing, as well as other related environmental and health sectors can applied this research to the automotive industry. Last but not least, metamaterials are distinguished from ordinary materials by their capacity to regulate and alter electromagnetic, optical, and acoustic waves. Metamaterials will be able to modify not just for sound absorption, but also for transmission, reflection, beam steering, heat conduction management, and other factors, which means it is flexible based on their tunability.

1.9 Thesis Organization

This project paper is organized as follows:

a. Chapter 1

This section introduced metamaterials and train/monorails noise level in Malaysia. This chapter listed the main objectives of this research paper, followed by the scope of work, methodology, flowchart, research expected outcome, and research contributions and commercialization. Other than that, this chapter also explains how this research is carried out specifically.

b. Chapter 2

This section contains a collection of various literature reviews related to this research paper; current noise of trains in Malaysia, allowable noise in train and previous research on metamaterials etc. This chapter covered research from a range of areas that was relevant to the research paper. Methods and standards for sound absorbing material studies are also addressed and given. This chapter also offers literature review summaries to emphasize the most important findings.