MODELLING OF NON- REVERBERANT ACOUSTIC SPACE USING STATISTICAL ENERGY ANALYSIS (SEA)

GOH JZUN HWEE

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Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka

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SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive)"

Signature: ………………………..
Supervisor: ………………………..
Date: ………………………..

DECLARATION

“I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged.”

Signature: ……………………….

Author: ……………………….

Date: ……………………….

DEDICATION

To My Beloved Family

Goh Hock Lim

Tan Siew Wah

Goh Yau Li

Goh Li Nee

Goh Li Xiang

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ABSTRAK

Analisis Statistik Tenaga (SEA) adalah satu kaedah yang terkenal untuk menganalisis vibro-akustik dalam system yang 'kompleks'. Teknik ini mengandaikan bahawa komponen (subsistem) struktur yang mengandungi bilangan besar untuk mod tempatan yang tidak boleh dimodelkan dengan tepat. Untuk kes subsistem ruang akustik, ruang seharusnya menyebar atau bergema bagi bidang bunyi. Kertas ini membincangkan bidang bunyi di dalam ruang akustik yang tidak bergema dengan medan komponen terus menguasai jumlah bunyi dari medan resapan yang diandaikan oleh model SEA. Oleh itu, model SEA mungkin tidak sah dan perlu diperbetulkan. Kotak ganding yang dibuat daripada keluli yang sederhana digunakan untuk mudah mengawal persekitaran akustik. Bagi kes keadaan yang tidak bergema, bahan penyerap diletakkan di dinding kotak. Pengukuran dijalankan dengan kotak dipisahkan oleh bahagian bukaan dan teknik suntikan kuasa dilaksanakan untuk mendapatkan faktor kehilangan gandingan. Keputusan yang munasabah untuk CLF yang diperolehi dari teori SEA selepas penyingkiran medan komponen terus dari jumlah tenaga bunyi untuk keadaan yang tidak bergema.

ABSTRACT

The Statistical Energy Analysis (SEA) is a well known method to analyze the vibro-acoustic of a ‘complex’ system. This technique assumes that a component (subsystem) of a structure contains a large number of local modes that cannot be modeled precisely. For the case of an acoustic space subsystem, the space should be made up of diffuse or reverberant sound field. This paper discusses the sound field inside the non-reverberant acoustic space where direct field component dominates the total sound rather than a diffuse field which the SEA model assumption is based on. Thus, the SEA model might not be valid and should be corrected. A coupled-box made of mild–steel is used to easily control the acoustic environment. For the case of non-reverberant condition, absorbent materials are placed on the room walls. Measurement is conducted in the box separated by a partition with an opening and the power injection technique is implemented to obtain the coupling loss factor. Reasonable agreement of CLF result from SEA with the theory is obtained after removal of the direct field component from the total sound energy for the non-reverberant condition.

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NOMENCLATURES

$\overline{\alpha_i}$ = Mean Absorption Coefficient Of The Surface

c = Speed Of Sound, ms^{-1}

$E_1^{(1)}$ = Measured Subsystem Energy, Db Re. 10^{-5} Pa

E_{dir} = Direct Field Component, Db Re. 10^{-5} Pa

$E_{rev,i}$ = Reverberant Field Component, Db Re. 10^{-5} Pa

$\widehat{E}_i$ = Normalized Energy (By The Square Pressure), Db Re. 10^{-5} Pa

E/N = Modal Energies

L = Matrix Of Coupling And Damping Loss Factors

M_o = Modal Overlap Factor

N = Total Number

N^2 = Large Dimension Of Energy Matrix

N_m = Modal Number

η_i = Damping Loss Factor Of Subsystem *i*

η_{ij} = Coupling Loss Factor Of Subsystem *i* to Subsystem *j*

ρ = Air Density, kgm^{-3}

P_{in} = Input Power

$P_{i,j}$ = Power Transfer Between Subsystems

P_{id} = Power Losses Between Subsystems

$P_{in,i}$ = Energy Balance For Subsystem *i*

$P_{diss,i}$ = Dissipated Power For Subsystem *i*

$P_{coup,i}$ = Coupling Power For Subsystem *i*

S = Surface Area Of Partition Between Subsystems

S_{xx} = Auto-Spectra From The Reference Microphone

S_{yy} = Auto-Spectra From The Response Microphone

NOMENCLATURES

S_{xy} = Cross-Spectra Between The Two Microphones

τ_{ij} = Transmission Coefficient

t_a = Arrival Time Of The First Reflection, s

V = Volume, m^3

ω = Centre Frequency Of Band B Or Radian Frequency, rad/s

$\omega(t)$ = A Simple Unit Step Window Function

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Early, 1990s, image source and ray tracing methods were commonly used to solve the calculation of interior noise at higher frequencies. More recently, Statistical Energy Analysis (SEA) methods have been commonly used to solve this problem (David, 2009). The development of SEA is in 1960 by Richard Lyon to investigate random vibration and vibration energy flow in structures. The relationship of power and energy was determined. The power flow was proportional to the difference in uncoupled energies of the resonators thus it always flows from the resonator of higher to lower resonator energy. A complex structure is divided into ’subsystems’ and then stored and exchanged vibrational energy between these subsystems are analyzed. Several advantages found by the energy-based approach used in SEA such as the energy quantities can be averaged more easily. However, there is a requirement that the subsystem must vibrate in resonant mode where modal overlap is high in a frequency band. In this condition, the details of the response are ignored, but rather the ’statistical’ average of the data. In 1960, SEA developed that Smith’s limiting vibration amounted to an equality of energy between the resonator and the mean modal energy of the sound field. Both calculations were therefore consistent and power flow between resonators until equilibrium (Lyon & DeJong, 1995).

Eicher (1963) introduced an important extension of the two systems theory and developed predictions for the energy distribution for three systems connected in tandem. The practical application of SEA often involves the flow of vibratory energy through intervening and parallel ‘substructures’. Therefore, it is important to predict the energy distribution. Prediction of system damping has improved. Although the improvements were not particularly related to SEA experiment, the experiment by Heckl (1962) on plate boundary absorption has found that the way of absorption coefficients vary with frequency is primarily a function of the geometry of the boundary structure. The SEA method of calculating the coupling loss factor between room and cavity given by Price and Crocker (1969) has proven that transmission from room to cavity is similar with transmission from room to room.

In recent years, Ming and Pan (2004) predicted the insertion loss of acoustical enclosures in different frequency ranges. SEA method has been also successful investigated of structural response and noise reduction of an acoustical enclosure by Lei (2012). According to Ahmida and Arruda (2003), the SEA coupling loss factor model has been estimated via the Spectra Element Method (SEM). SEA can be used for prediction of the interior sound field in vehicle (Forssen, 2012), prediction of Sabine absorption coefficient of modally reactive panels (Sum & Kim Seng, 2005), prediction sound transmission through double walls with using coupling loss factor room to cavity undertimes the coupling (Robert, 2003), prediction of impact sound transmission in building acoustic (Kim & Shon, 2001) and prediction of transmission loss in building structures (Koizumi & Tsujiuchi, 1999).

SEA is a method for mid to high frequency noise and vibration analysis. This technique assumes that a component (subsystem) of a structure contains a large number of local modes that cannot be modeled precisely (Belyaev & Langley, 2010). For the case of an acoustic space subsystem, the space should be made up of diffuse or reverberant sound field. According to Sarradj (2004), SEA model can be divided into subsystems and there are no formal criteria and no systematic approach for division. Subsystems are physical element of the structure which there is dissimilar discontinuities in physical properties (thickness, mass density, wave type etc). As excitation is subjected to the subsystem and then turn off, the subsystem should vibrate in resonant mode. That mean the vibration energy stored in the subsystem was decay. Thus, a reverberant sound field exists within the subsystem. Some examples of vibro acoustic subsystems are listed such as an acoustic cavity (a room), a plate, a beam, shells, and non-isotropic plates.

The modelling technique introduced by Renji (2001), that modified SEA formulation by the nonresonant response can also be predicted. Modelling for nonresonant response is similar to the conventional SEA modelling for resonant response but uses different expressions for the coupling loss factor. SEA are widely used in aerospace industry, ship building industry and building acoustics, and efforts have been undertaken to model vibration transmission through structural junctions. Meanwhile, SEA started involves in commercial software like the other analysis methods (2010).

1.2 PROBLEM STATEMENT

The treatment of an acoustic space with absorber materials such as the car interior makes it space not fully reverberant, but dominates by the direct field component. Therefore, the classical SEA model might fail to predict the ‘correct’ sound pressure level.

1.3 OBJECTIVE

This project consists of the following objectives:

1. To investigate the effect of direct field component on a SEA model of acoustic space subsystems.

2. To investigate the sound field inside an acoustic space using the corrected SEA model by eliminate direct field component.

3. To validate the theoretical with experiment.

1.4 METHODOLOGY

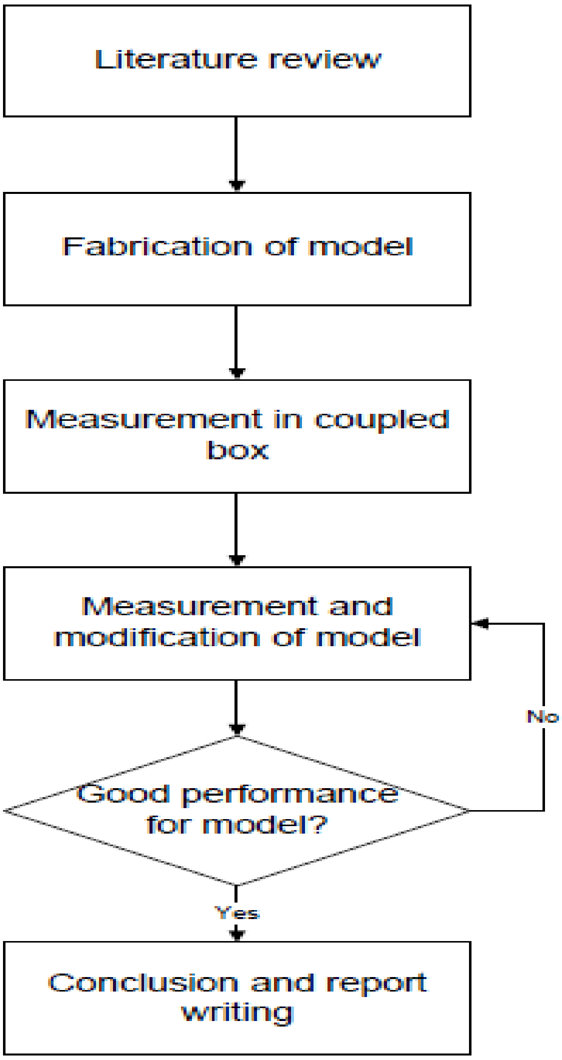

Figure 1 1: Methodology flow chart

Figure 1.1 summarizes the methodology into a flow chart diagram. Firstly, literature reviews that related to Statistical Energy Analysis (SEA) were studied and summarized into the report. These literatures could be journals, articles, academic books and other related references. After that, the testing model was designed and fabricated in the workshop by appropriate equipments. The material of model is mild steel with thickness 2 mm and 3 mm for box and coupling respectively. The mild steel plates were sheared into appropriate dimension. The plates were placed accordingly for welding purpose. The corners of plates were welded. After completed, all corners of box were ground before silicone gum was applied along the edges of the box for sound insulation. The next step will be the measurement in coupled box. The coupled box can be easily controlled by placing absorbent materials on the room walls to reduce the reverberant effect. Measurement is conducted in the box separated by a solid partition made of same material with an opening of 50 x 50 mm at the middle for reverberant condition and non-reverberant condition. The power injection technique is implemented to obtain the coupling loss factor.

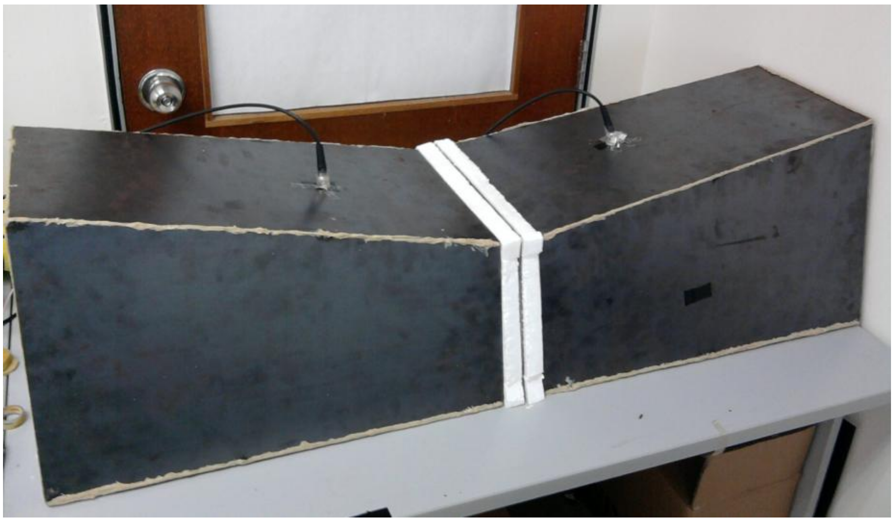

Figure 1.2: Coupled box

Figure 1.2 shows the coupled box made of mild steel plates is used to easily control the acoustic environment.

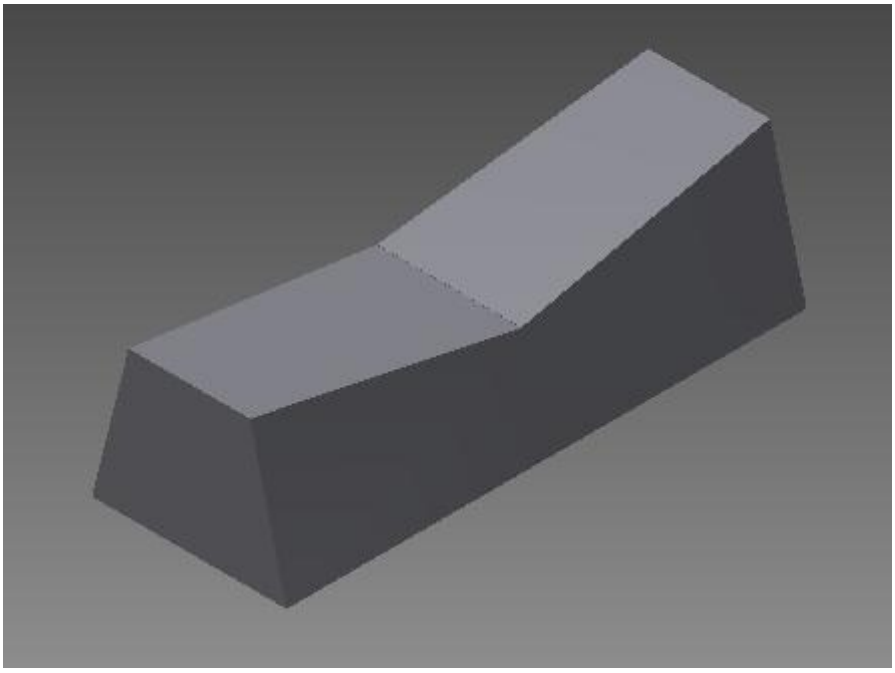

Figure 1.3: Cad drawing of coupled box

Figure 1.3 shows the cad drawing of coupled box by Autodesk Inventor.

1.5 SCOPE

1. The experiment is simulated using two coupled boxes which is easy to control.

2. A method to remove direct field component from sound pressure signal will be investigated.

CHAPTER 2

LITERATURE REVIEW

Noise can be classified into two categories, namely **structure borne** and **airborne**. Structure-borne is noise that produced by direct vibration of the walls. Airborne noise is noise generated through the air before reaching a partition. These noises can be insulated by adding sound dampening materials (Hosseini Fouladi,et.al. 2009).

Reverberant field is a free field that exists only under specific test conditions. Outdoor condition can approach it. Indoors, the interaction of the reverberant field and direct field can be observed as the sound source is moved away. Figure 2.1 shows the illustration of the reflections in an enclosed space compared to direct sound at a variable distance from the sound source (Rayburn, 2011).

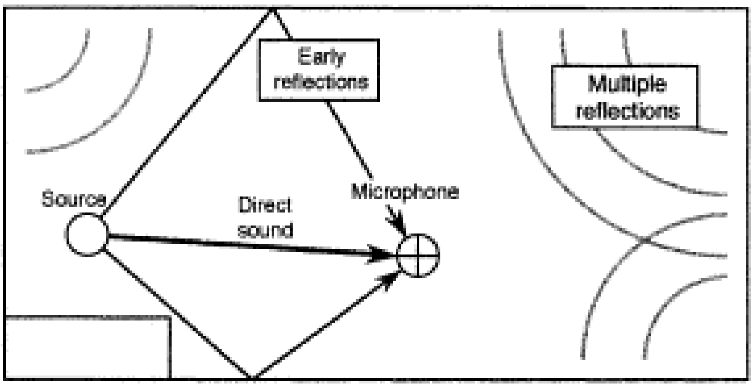

Figure 2 1: The reverberant field; illustration of the reflections in an enclosed space compared to direct sound at a variable distance from the sound source (Rayburn, 2011).

Ribeiro and Smith (2005) investigate sound pressure level distribution due to one or more sound sources in a large acoustic space by using SEA. The sound field inside an industrial workroom may be predicted by the resulting model. It is generally not possible to assume the a uniform reverberant field throughout the room due to the attenuation and scattering of the sound field with distance in such spaces. A separate treatment of direct field and reverberant sound fields was predicted on the model. Application of corrections such as barrier theory was required for the direct sound field which was assumed to be free-field propagation (no obstacles are located between the source and the receiver). SEA framework with the power input corrected for energy lost at first reflection was used and analyzed for the variation of the reverberant field around the room. The sum of the direct field and reverberant fields represent the total sound pressure level at any receiver point. Three distinct subsystems were formed from the acoustic space for measurements of a workroom using experimental SEA methods. The presence of direct field affected the SEA parameters result Experimental and theoretical predicted SEA parameters have been compared. The coupling loss factors shown good agreement but the damping loss factors estimated were less well with the measured data.

Recently, sound propagation of a Swedish Regina train with five compartments has been modelled using statistical energy analysis (SEA) and validated by a ray-tracing method and scale model measurements. The train compartments' sound field is treated as a series of connected air cavities. The excitation source is located in second cavity among five cavities in series. The materials for scale model are medium-densiy fiberboard (MDF) and acrylic glass (Makrolon®). The final scale model is shown in Figure 2.1. The SEA model is adjustable and predicted for the rate of spatial decay within a cavity. For the ray tracing modeling, a full-scale geometry drawing by commercial 3-D software was imported to software Odeon® version 9.1 for analysis. A point source was defined at the same position as where the actual source was located. Result was obtained after 30 min. For SEA model analysis, the train compartments were divided into five subsystems which represented the total of three saloons and two vestibules. A sufficiently large model overlap factor is needed for the SEA model to be valid. Between the results from measurements, the ray tracing and SEA model, for two saloons closest to the source cavity have shown good agreement for the octave bands