

PARAMETRIC STUDIES ON
MUFFLER INTERNAL GEOMETRY RELATED TO
SOUND TRANSMISSION LOSS AND PRESSURE DROP

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ABSTRACT

Muffler is a device to attenuate noise generated in the exhaust gas. Based on the current noise regulation, automotive manufacturer was forced to improve the muffler performances. Parametric approach was used to improve the existing muffler performances rather than designing a new muffler. The research aim was to investigate the effect of main muffler internal geometry towards STL and PD across the muffler. A comprehensive parametric study was conducted to analyse the effect of muffler internal geometry towards its performance. Two mufflers were selected in this research work; one simple expansion chamber and the other was a complex muffler 1.6 litre natural aspirated engine. Both mufflers performances were measured experimentally using impedance tube and SuperFlow bench machine. The simple expansion chamber was used to validate the proposed concept of 1D model generated by Ricardo WAVE meanwhile, the complex muffler was used for comprehensive parametric studies to investigate the effect of internal muffler geometry towards STL and PD using the 1D model. Four parameters were examined, namely main shell volume, pipe diameter, perforated baffle and perforated pipe. The effect of internal geometry was analysed from the parametric studies. When the muffler volume was increased, the average STL was increased and the PD was reduced, respectively. When the diameter of the pipe was increased, the average STL and PD were dropped. The perforated on baffle showed less effect on average STL where it can increase by a maximum of 1 dB. However, the PD showed a reduction trends as the perforated on baffle was increased. The perforated on pipe shows major effect at 600 Hz only and PD reduced as the perforated on pipe was increased. From the parametric studies, the STL was mostly affected by the muffler main volume while PD was affected by the pipe diameter. In order to minimise the PD, the perforated was introduced to the muffler design. Adding a resonator and increasing the baffle spacing help to improve the muffler performances. As a result, the complex muffler was successfully optimised with an increase in average STL by 3.59% and maintained the PD.

ABSTRAK

Peredam bunyi (PB) adalah sebuah peranti bagi mengurangkan bunyi yang terhasil dari pelepasan gas ekzos. Berdasarkan kepada peraturan bunyi semasa, pengeluar automotif telah di sarankan untuk menambahbaik prestasi PB. Pendekatan parametrik telah digunakan untuk menambahbaik prestasi PB sedia ada berbanding dengan mereka bentuk PB yang baharu. Tujuan penyelidikan ini adalah untuk mengkaji kesan dalaman geometri utama PB terhadap kehilangan penghantaran bunyi (KPB) dan susutan tekanan (ST) PB. Kajian parametrik yang komprehensif telah dilakukan dalam menganalisis kesan geometri dalaman PB terhadap prestasinya. Dua buah PB telah dipilih di dalam kajian penyelidikan ini; satu kebuk pengembangan mudah (KPM) manakala satu lagi adalah peredam bunyi kompleks (PBK) 1.6 liter enjin sedutan semulajadi. Prestasi kedua-dua PB ini di ukur secara uji kaji menggunakan tiub galangan dan mesin meja SuperAliran. KPM telah digunakan untuk meng sahihkan konsep model 1D yang dihasilkan oleh Ricardo Wave manakala PBK digunakan untuk kajian keseluruhan parametrik bagi mengkaji kesan geometri dalaman PBK terhadap KPB dan PD menggunakan model 1D. Empat parameter telah dikaji iaitu isipadu kelompang utama, garis pusat paip, sesekat tertebuk dan paip tertebuk. Kesan geometri dalaman telah dianalisis dari kajian parametrik. Bila isipadu PB meningkat, purata KPB meningkat dan ST berkurang. Bila garis rentas paip meningkat, purata KPB dan ST menurun. Prestasi sesekat tertebuk menunjukkan kesan yang kurang terhadap purata KPB dengan peningkatan maksimum sebanyak 1 dB sahaja. Walaubagaimanapun, ST menunjukkan tren penurunan apabila tertebuk pada sesekat meningkat. Paip tertebuk menunjukkan kesan yang besar pada 600 Hz sahaja, dan ST berkurang apabila tertebuk pada paip meningkat. Dari kajian parametrik, KPB banyak dipengaruhi oleh isipadu utama PB manakala ST pula dipengaruhi oleh garis pusat paip. Untuk meminimumkan ST, tebuk telah diperkenalkan kepada reka bentuk PB. Dengan menambah penyalun dan meningkatkan jarak sesekat, dapat membantu memperbaiki prestasi PB. Hasilnya, PBK telah berjaya dioptimumkan dengan peningkatan purata KPB sebanyak 3.59% dengan mengekalkan ST.

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LIST OF ABBREVIATIONS

1D	One-dimensional
3D	Three-dimensional
BP	Back pressure
CFM	Cubic feet per minute
CID	Cubic inch displacement
DAQ	Data acquisition system
EU	European Union
IL	Insertion loss
ITM	Integrated transfer matrix
NA	Natural aspirated
PD	Pressure drop
PLC	Pressure loss coefficient
RPM	Revolution per minutes
SPL	Sound pressure level
STL	Sound transmission loss
TL	Transmission loss
VE	Volumetric efficiencies

LIST OF SYMBOLS

$ H^c $	Amplitude
m	Area ratio
H^c	Correction transfer function
dB	Decibels
ΔP	Delta pressure
ρ	Density
H^I	Direct transfer function
R	Gas constant
γ	Heat capacity ratio
M_c	Mach number
\dot{m}	Mass flow rate
s_1, s_2	Microphone spacing
L, d	Muffler length
k	Natural frequency
φ^c	Phase mismatches
P	Pressure
ξ	Pressure loss coefficient
c	Speed of sound
H^{II}	Switched transfer function
T	Temperature
T_{11}	Transfer matrix
TL	Transmission loss
d	Tube diameter
f_u	Upper frequency
V	Volume

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CHAPTER 1

INTRODUCTION

1.1 Background Study

The muffler is a device used to attenuate noise generated from the engine. The noise generated from the engine is transmitted through the exhaust gas. Along the exhaust gas path, the gas will meet up the muffler. As a result, the noise energy carry in the gases is attenuated.

Muffler divided into two types which are the reactive muffler and dissipative muffler. The reactive muffler mechanism operates by using the wave cancelation between the incident wave and the reflected wave. Thus, the positive wave and negative wave hit opposite and create noise cancelation effect. The dissipative muffler mechanism is based on the absorptive principle. The softer the material, more sound are absorbed and attenuate.

To create noise cancelation, the internal geometry of the muffler plays a big role. The internal geometry of the muffler consists of the volume of the chamber, shape of the chamber, inlet and outlet diameter, porosity of the perforated type, baffle spacing and baffle number.

A muffler with a various internal geometry also knows as complex muffler. Complex muffler defined as the muffler with a various geometry inside the muffler such as baffle plate, extended pipe, bend pipe, perforated pipe, perforated pipe, unique perforated arrangement and come with resonator.

The muffler performance commonly measured based on two parameter which are sound transmission loss (STL) and pressure drop (PD). To determine the muffler

performances, all the parameter can be determined theoretically, experimentally and computer simulation.

1.2 Problem Statement

Muffler is a device to attenuate noise generated in exhaust stream. With the current enhanced and stringent noise regulation by the country like Japan and organization such as European Union have forced the automotive manufacturer to improve the muffler noise absorption. While having a better muffler noise absorption, the pressure drop of the muffler must be maintained because the engine performances cannot be compromised. Furthermore, the noise generated from the exhaust can provide a low ride comfort and lead stress to the driver especially the low frequency noise. Despite of having a newly design muffler, improving the existing muffler model by modified the internal muffler geometry can produce a good muffler sound absorption and maintain the pressure drop. Identifying a specific parameter through parametric study on the internal geometry study with major effect towards sound absorption and pressure drop can help the automotive manufacture to improve the existing muffler design. Moreover, the current technique used by some of automotive manufacturer are try and error method to get the results.

Parametric studies can be conducted through a simulation process that save a lot of money and time. One of the important approaches is 1D modelling and 3D modelling. Instead of using a 3D modelling tools that is time consuming, 1D modelling are more convenient with less time taken and with acceptable accuracy. Hence, this study focuses to identify the muffler internal geometry effect through parametric study and with the finding from the parametric studies, the result was used a guideline to improve the muffler performances by using a 1D simulations. One complex muffler for current commercial muffler had been selected for this study. This muffler was chosen because of the internal geometry less complexity compare to another commercial muffler that are more complex than the selected muffler.

1.3 Research Objectives

The objectives of the research are:

- i. To determine the current exhaust muffler sound transmission loss and pressure drop using 1D simulation and experiment.
- ii. To analyse the effect of exhaust muffler internal geometries toward the sound transmission loss and pressure drop.
- iii. To optimise the current exhaust muffler model by increasing sound transmission loss at least 3% and maintain the pressure drop.

1.4 Research Significant

The research will be conducted based on the problem statement described in Section 1.2. The new proposed muffler design will have a better sound transmission loss (sound absorption) and maintain the pressure drop. The findings from this research work can become references for the vehicle manufacturer to improve their muffler performances with the existing muffler design. The method used in this research will be discussed briefly and comprehensive parametric studies were conducted. Finding from the parametric studies were used as guideline to improve the existing muffler design. Understand effect of internal arrangement is a critical aspect that will lead to a better acoustic design. Combination of different internal configurations can provide benefits to automotive manufacturer.

Parametric studies will run using a 1D simulations tools. The 1D tools were choose because it saves time with acceptable accuracy. Furthermore, the engine simulation also was done in 1D simulation. By doing this, it can help the automotive manufacturer to improve their existing muffler design with a minimal cost and save a lot of time. Furthermore, this study filled the gap between the 1D and 3D analysis of sound transmission loss and pressure drop.

1.5 Research Scope

- i. Two specimens used, simple expansion chamber and complex muffler.
- ii. The simple expansion chamber was design to be use as 1D model validation before proceeded with complex muffler.
- iii. The muffler model used for parametric studies was a complex muffler 1.6 Liter natural aspirated (NA) engine.
- iv. Validation of simple expansion chamber and complex muffler performances between 1D simulation and experiment at frequency below 1000 Hz.
- v. The research focused on the main exhaust muffler and four parameters of internal geometry; volume, pipe diameter, perforated baffle and perforated pipe.
- vi. The studied performances consist of sound transmission loss (STL) and pressure drop (PD)

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