DESIGN AND CONSTRUCTION OF A REACTIVE TYPE MUFFLER FOR A FORMULA STUDENT VEHICLE

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ABSTRACT:

A Muffler is a noise controlling device that is utilized to reduce the sound formed by the exhaust gases pushed out from an IC engine. There are many types of mufflers based on engine speed, torque, and horse power. Upon Formula SAE guide lines the teams entering the event primarily aims to design and build a new exhaust system that will not exceed 100 dB and 110 dB at an idle speed and all supplementary speeds respectively. The secondary works aims to produce a system with an optimization in weight, cost and rise in overall engine performance. This paper work includes determining the dimensions of primary header tube and muffler, performing flow analysis by iterative trial and error technique and construction of a reactive type muffler for a formula student prototype vehicle using Stainless Steel tubes and Galvanised Iron sheets. Trialing found that muffler design 2 attenuates sound 86 db and 101 db at idle and supplement speeds respectively without creating much backpressure.

Keywords: Formula SAE, primary header, muffler, flow analysis.

1. INTRODUCTION:
An exhaust system is an important sub-system of automobile which is utilized to bring down the contamination regarding noise and in addition toxics in the earth. It is used to eliminate the after burnt fuels and leftovers from the combustion chamber through a sequence of elements. Among those elements muffler plays a central role in attenuating the sound produced by the vibration of molecules in the path of the exhaust outflow.

Mufflers are categorized into:
1. Reflective Muffler
2. Dissipative muffler

In other terms they can also be classified as:

a) Restrictive exhaust system muffler.
b) Performance exhaust system muffler.

There are some parameters to be kept in view while designing a muffler. They are
1. Sound to be attenuated
2. Space frame available
3. Effect on engine performance
4. Economy.

In this work the design and construction of a muffler was done for a formula student prototype vehicle which runs on KTM duke 390 engine. It deals with a reflective muffler which is designed as acoustic soundproofing device in order to minimize the noise around the exhaust system. A muffler has baffled chambers or perforated tubes which are actually pitched as a musical gadget. The sound motion travels through the baffled chambers or perforated tubes, the opposing waves cancel each other the original waves.

2. LITERATURE SURVEY:
The improvement of muffler dates back to 1920’s. There have been significant changes in the design of muffler. Also different theories we developed to understand various parameters like mass flow rate, volumetric flow rate, transmission losses, insertion losses, pressure drop, back pressure effects, calculate the chamber lengths. Many investigational activities have been performed and still being carried to optimize the performance of exhaust system without effecting the performance of engine. Vijay M Mundhe[1] studied the performance of silencer by analyzing the flow pattern and pressure variation, giving input in the form of sinusoidal wave k-epsilon method is deployed to obtain required outputs with and found that design 1 was more effective. A. I. Komkin [2] in his work stated that the frequency in the muffler is based on the engine system parameters to which the muffler is set. The performance of a prototype can be maximized by the use of integral criterion of acoustic performance which is a function of overall transmission losses and also non dimensional geometrical parameters for electrical filter calculation. Ying-chun [3] derived transmission losses by using decoupled numerical method and evaluated the acoustic performance of the muffler using four pole matrix system. Using the algorithm of simulated annealing he tried to optimize the working of multi flow chambered muffler with reverse flow ducts and found it to be reliable. A higher iteration will lead to a set of enhanced shape design data. Min-Chie CHIU [4] worked to study the combination of absorptive and reactive type muffler within space constrain. Genetic algorithm was employed to assess the transmission losses alongside four-pole matrix system which is used to think about the acoustical performance. Final results indicated that sound is reduced to approximately to 85dB from 140dB. M.Rahman[5] and his team worked in designing and fabricating a hybrid automotive muffler using the principles of wave
interference to attenuate high frequency and low frequency noises along with a tunable resonator to lower other left over low frequency waves. The obtained results seemed to have an insertion loss of 30dB to 35dB. Vaibhav[6] worked on providing better modifications to an existing muffler of Maruti Suzuki WagonR, there were six proposed designs which were analyzed to study the flow in the muffler. Pressure drop, back pressure ,noise reduction are compared for all the models and found that design 1 and design 6 serve better than the conventional one. Indira Priyadharshini [7] concentrated on decreasing the back pressure as it reduces the power obtained from the engine. Flow trajectories are observed and the results interpret that second variant gives a better performance with least pressure drop. Takashi Yasuda[8] performed research on the tail pipe of the muffler which is used to lower the noise from the engine for its acoustic performance of low pass filter. The muffler’s performance is assessed using time domain frequencies. The mufflers having interconnecting hole on the tail pipe is formed using acoustic electronic theory by the frequency equation. Outcome showed that muffler had attenuation performances of low-pass filter and Helmholtz resonator when a interconnecting hole was designed on the tailpipe. To keep a good attenuation performance at low frequency field, the continuous hole should be located on the tail pipe as front as possible.

3. MUFFLER DESIGN PARAMETERS:
Reactive mufflers are classified into two categories on the basis of the direction of mean flow of exhaust gases through them:
1. Straight-through mufflers,
2. Reversed flow mufflers.

Here modelling a straight through muffler with a series of chambers in it. Fore hand must know the parameters like insertion losses, transmission losses and effect of back pressure to evaluate the performance of the silencer.

**Insertion losses** can be defined as the difference in levels of sound produced before and after use of a muffler as an acoustic filter.

**Transmission losses** are independent of sources. The variation between the power falling on a duct acoustic device and that transmitted downstream into an anechoic termination is known as Transmission losses.

**Back pressure** is the extra static pressure applied by an acoustic filter on the engine by the confinements in the flow of gases. This should be minimized which otherwise on a 4-Stroke engine would affect the volumetric efficiency, brake power and also specific fuel consumption rate.

3.1. DESIGN OF HEADER:
Knowing the dynamics of fluid flows significantly helps in deciding the diameter and length of the primary header tube which is likewise known as runner. During the suction stroke the pressure impact in the combustion chamber is not excess than 0.3bar So in a naturally aspirated engine the air fuel mixture enters the combustion chamber using the basic principle of pressure distinction. Although the burnt gases are thrown out of the engine at the last stage of exhaust stroke there will be some residual gases present in the cylinder chamber. A procedure is employed to diminish these trapped gases called scavenging. In this process between the period of valve overlap the fresh charge with higher density entering the combustion chamber pushes out the residues into the atmosphere though the manifold. Usually during the exhaust push the gases pushing out with a rapid velocity enters the exhaust manifold then travel through the runner and to the acoustic filter and lastly to the atmosphere. As the gases travel with a high velocity, due to inertial effects the alternate gas atoms around
the exhaust gas flow gets pulled alongside with it into the atmosphere this making a down pressure pulse behind the stream of gases. This negative pulse travels in backward direction towards the exhaust valve to empty the residual gases in the combustion chamber of engine during scavenging. However the exhaust gases speed varies depending on the diameter as well as the length of the runner. If the diameter of the runner is less, then the velocity of the out coming gases increases and pressure decreases which decreases the back pressure and increase the volumetric efficiency of the engine. However it does not constrict the sound to the required level. If the runner diameter is more than required then the velocity decreases and pressure increments according Bernoulli’s principle. So back pressure gets formed on the which reduces the scavenging thereby diminishing the volumetric efficiency finally leading to the decrease in performance of the engine. From the above theory in order to achieve the time owed by the negative pressure wave to travel to the exhaust valve and to support scavenging, calculate runner length and diameter and obtain optimal performance at the muffler end. It is to be noted that the output of the runner is the input of the muffler. By techniques of conservation of mass, a small diameter exhaust pipe will bring out in higher gas speeds, conducive to throttle response for acceleration. As mentioned above without adequate cross sectional zone, little diametric pipes may restrain the mass stream rate needed to expel all combusted gases at higher rpm. For proper ‘backpressure’ or ‘scavenging’, a perfect length is required to allow for reflected pressure waves to arrive back at the exhaust port in time for the valve overlap period. Changes in exhaust gas temperature throughout the engine results in a dynamic speed of sound and therefore the optimum length can only be accounted for an engine speed and its modes thereafter. Also, any change in geometry within the exhaust system will result in reflected pressure waves, which significantly affects the length of the header pipe.

Because of the complicated nature of the scavenging effects, literature reviews often provide guideline equations which are suited to a specific engine assuming an ideal straight exhaust pipe. Two equations by Smith (1972) and Bell (1988) give approximate lengths from cylinder characteristics at expected engine speeds.

\[ P = \frac{850 \cdot ED}{R} - 3 \]  

(1)

Where
- \( P \) represents pipe length in mm,
- \( ED \) is 180 plus the number of degrees the exhaust opens before BDC (bottom dead center),
- \( R \) is the rpm at required target

Once the pipe lengths has been known then calculate the internal diameter using the following formula

\[ ID = \sqrt{\frac{cc}{(p+3)\cdot25}} \times 2.1 \]  

(2)

\( ED = (180+55) \)
\( R = 9000 \)

From (1) We get = 487.426mm

= 19.19 inch

From (2) we get = 43.688 mm

= 1.72 inch
3.2. DESIGN OF MUFFLER:

An automotive reactive muffler works on the principle of destructive interference. In this when two pressure waves have relocation in inverse direction it results in noise cancelling effort that muffler designers use on specific frequencies to quiet them and leave behind the deserved frequencies. A reactive muffler has a series of chambers and perforated plates and tubes at expected position to disfigure the sound waves leaving out of engine. These methods require the sound waves to reverse back around and reach react against the pressure pulse. This principle can be known as reflective sound cancellation technique. Here, primarily the low frequency sound waves are redirecting them into chambers and specially designed channels and reversing the flow causing the sound waves to cancel themselves out and dispense undesirable frequencies.

There are basically three ways to calculate the chamber length. They are
1. Range of chamber length based on wavelength of sound
2. Range of chamber length based on varying exhaust temperature.
3. Range of chamber length according ASHRAE technical committee.

Calculations for chamber length based on ASHRAE

There are different grades of mufflers depending upon the insertion loss and required attenuation of the sound should be nearly by 35dB. Analysing the parameters of a super critical grade muffler whose calculations are as follows.

SUPER CRITICAL GRADE

PARAMETERS = Insertion loss = 35 to 45 dB
Body to Pipe ratio = 3
Length to Pipe ratio = 10 to 16
Body diameter = 3 * 1.7
Baffle diameter = \( \frac{\pi d^2}{4} = \frac{\pi}{4} (d_1)^2 + \frac{\pi}{4} (d_2)^2 \)

Here \( d_1 = d_2 \)
So \( \frac{\pi d^2}{4} = 2 * \frac{\pi}{4} (d_1)^2 \)
So \( d_1 = 1.2in \)
Muffler length: 10 * 1.7to 16 * 1.7
Muffler body Diameter = 129.54mm
Muffler length(Average) = 561.34mm
Baffle Diameter = 30.48mm
4. MODELLING AND ANALYSIS:
Based on the above calculations, Modelling and simulation of muffler is done and studying its flow trajectories within in each chamber of the reactive muffler. The advantage of SOLIDWORKS modelling and simulation software is utilized to carry our work forward.

MUFLER DESIGN ➔ 1 (Units in mm)
- Inlet wall with a hole of 43mm diameter
- Baffle plate_1 at 191 mm from inlet wall with two holes of 30mm diameter
- Baffle plate_2 at 381 mm from inlet wall with 3 holes, two of 30mm diameter and one with 43mm diameter
- Chamber_2 division is such that on baffle plate_3 one 30mm diameter hole lies on one side of the divider and another 30mm diameter hole with 43 mm diameter hole on the other side of the divider and on baffle_2 on of 30 mm diameter hole diameter lies on one side and another on the other side
- Chamber_3 division such that on baffle_3 both the 30 mm diameter hole lie on the same side of the divider and the 43 mm diameter hole lies on the other side.

Figure 2 shows Model of Three chambered muffler with baffle plates with no perforated tubes.
4.1. BOUNDARY CONDITIONS:
A Volumetric Flow of 0.02954 m$^3$/s at the inlet wall of the muffler and an Atmospheric pressure of 101.325 KPa. The Perforated tubing running through the baffle plates are eliminated while performing the flow analysis. Equation of continuity reveals that the exhaust gases come out with a velocity of 40.66 m/s at a constant air flow of 9500 Rpm. The Meshing size is taken as 4 (course).

FLOW ANALYSIS OF MUFFLER_1

Figure 3 shows Flow analysis of three chambered muffler with baffle plates with no perforated tubes.

CUT PLOT ANALYSIS OF MUFFLER_1:

Figure 4 shows Cut Plot analysis of three chambered muffler with baffle plates with no perforated tubes.

FLOW TRAJECTORIES:
Here it is noted that in chamber 2 one division is having more pressure than the other one so the entire flow is choosing to flow through the other chamber which is having low pressure so there is no complete utilization of all the chambers which means that they are not attaining required insertion loss So this design was a failure and a need to design a muffler such that all the chamber will be having equal amount of pressure on both sides of the divider and there will be gradual decrease in pressure from one chamber to the next consecutive chamber so
there will be a gradual increase in velocity of the flow which is the main reason for the origin of the sound.

**MUFFLER DESIGN**

- Inlet wall with a hole of 43 mm diameter.
- Baffle plate_1 at 127mm from the inlet wall with two holes one of 30mm diameter and other of 43mm diameter.
- Baffle plate_2 at 254 mm with 3 holes, two of 30 mm diameter.
- Chamber_2 division such that on baffle_3 one 30 mm diameter hole lies on one side of the divider and another two 30 mm diameter holes on the other side.
- Chamber_3 division such that on baffle_4 the 30 mm diameter hole lie on one side of the divider and the 43 mm diameter hole lies on the other side.

**Figure 5** shows Model of Four chambered muffler with baffle plates with no perforated tubes.

The boundary conditions are same as above for the Model_1 Flow Analysis.

**FLOW ANALYSIS OF MUFFLER_2:**

**Figure 6** shows Flow analysis of four chambered muffler with baffle plates with no perforated tubes.
CUT PLOT ANALYSIS OF MUFFLER_2:

Figure 7 shows Cut Plot analysis of Four chambered muffler with baffle plates and internal divisions with no perforated tubes.

FLOW TRAJECTORIES:
If we see this design the pressure on both sides of the divider in the chambers are nearly equal which leads to complete utilization of muffler volume that means there is a better attenuation of sound as it is colliding more obstacles than noting down the values of decibels at idle previous one.

5. CONSTRUCTION:
The following are the list of different Dimensions to be made out of Galvanized Iron Sheets for the construction of MUFFLER of reactive type – super critical grade. GI Sheets are abundantly available at a cheaper price as well as resistant to corrosion. It can also withstand high temperatures. So, it makes one of the best alternative material for construction of muffler in trial and error method.

One GI Sheet of dimensions 500mm*400mm*1.25mm is rolled out to make a cylindrical Muffler Outer Wall.

Baffle plates with holes of required dimensions to insert the perforated tubes of 130mm diameter – 5No’s

Milled perforated sheets of
Thickness -2mm Holediameter-3mm
(Dimensions- 127mm length & 43mm diameter)
(Dimensions-127mm length & 33 mm diameter)
(Dimensions-127mm length & 25mm diameter)
RUNNER - (Stainless steel) thickness-1.2mm
Dimensions - 305 mm length and 38mm diameter
L-BENDS - (thickness-1.2mm & 38mm diameter)
(thickness-1.2mm & 44mm diameter).
Figure 8 shows Assembled prototype of Header and Reactive Muffler

6. RESULTS:
From the above flow trajectorial analysis, figuring that Muffler design_1 has not been able to utilize the chambers effectively. From fig-8 the muffler along with the runner is attached to the exhaust manifold of KTM Duke 390 engine. So to establish a low cost experimental setup analytically and evaluate the system, muffler is directly hinged to the engine and run at a varying rpm. A decibel meter is used to measure the sound produced in different muffler designs at different RPM’s as shown in the table below. The decibel meter is placed 15cm from the end of tail pipe at an angle of 45° and the sound from the wave pulses generated at the engine coming out from the muffler is measured.

<table>
<thead>
<tr>
<th>RPM</th>
<th>STOCK AFTER MARKET MUFFLER</th>
<th>MUFFLER DESIGN 1</th>
<th>MUFFLER DESIGN 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>90</td>
<td>90</td>
<td>86</td>
</tr>
<tr>
<td>4000</td>
<td>96</td>
<td>94</td>
<td>92</td>
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<td>6000</td>
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<td>100</td>
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<td>105</td>
<td>101</td>
</tr>
<tr>
<td>10000</td>
<td>115</td>
<td>108</td>
<td>105</td>
</tr>
</tbody>
</table>

7. CONCLUSION:
From the flow trajectories of design-1 and design-2 it is concluded that design-1 has failed as the pressure got accumulated in one of the divisions of chamber 2 which will lead to back pressure effecting the performance of engine while design 2 is having gradual pressure drop with a smooth flow putting a negligible negative effect on the performance of the engine.

From the above values obtained by practical analysis it is found that muffler design 2 have achieved the required level of sound reduction at specific rpm’s when compared with muffler design 1 and a stock muffler.

Muffler design 1 and design 2 have failed in terms of mass optimization in comparison with the stock muffler due to selection of material as well as working principle. The stock muffler is absorptive type which always weighs a bit lesser than reactive type mufflers.

The Muffler design 1 & 2 are economical and can be easily constructed using conventional tools & equipment. Its performance does not deteriorate as like the while the performance of stock dissipative muffler decreases over a period of time.
REFERENCES:


