A Review paper on Design of Muffler toward Reduce Sound in Exhaust System of IC Engine

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Abstract—Mufflers are commonly used in a wide variety of applications. Industrial flow ducts as well as internal combustion engines frequently make use of silencing elements to attenuate the noise levels carried by the fluids and radiated to the outside atmosphere by the exhausts. Restrictive environmental legislation requires that silencer designers use high performance and reliable techniques. Various techniques are currently available for the modelling and testing of duct mufflers. Empirical, analytical and numerical techniques have been used and proved reliable under controlled conditions. Design of a complete muffler system is, usually, a very complex task. Each element is selected by considering its particular performance, cost and its interaction effects on the overall system performance and reliability.

Exhaust noise from IC engines is one of main factor noise contamination to the atmosphere. Day by day, noise pollution increase in our environment due to increase of number of vehicle. Most of the advances in theory of acoustic equipment and exhaust mufflers have been developed in last decades. For the same power rating, diesel engines are noisier than gasoline engines, since the combustion characteristics of diesel engines produce more harmonics than slower combustion of gasoline. An unmuffled gasoline engine radiates exhaust noise in the range from 90 to 100 dBA while an unmuffled diesel engine under identical conditions radiates exhaust noise in the range from 100 to 125 dBA. Numbers of diesel vehicles are increasing as revolution in diesel engine. Therefore this has become an important area of research and development. Exhaust systems are developed to attenuate noise gathering necessary db levels and sound quality, emission should be base on environment norms.

Mufflers are designed to dampen the high intensity pressure pulse generated by the combustion process from an internal combustion engine. Muffler design is traditionally a trial and error process. This is due to the tricky nature of several different properties coming together in a way that they cannot be considered at once.

Mufflers are important element of engine system and frequently used in exhaust system to minimize sound transmissions caused by exhaust emission. Design of mufflers is a multifarious function that affects noise characteristics, emission and fuel efficiency of engine. However, the theories and science that has undergone expansion in recent years has given a way for an engineer to cut short number of iteration. In today’s competitive world market, it is important for a company to shorten product development cycle time

Keywords:Muffler, Exhaust noise reduction, Design
I. INTRODUCTION

As the invention of the internal combustion engine, the noise created by it has been a constant source of problem to the atmosphere. So the problems of reducing engine noise consist, mainly in attenuating exhaust noise. Good design of the muffler should give the best noise reduction and offer optimum backpressure for the engine. Moreover, for a given internal configuration mufflers have to work for a broad range of engine speed.

Frequently when mufflers are designed by well recognized numerical techniques like BEM (boundary element method) or FEM (finite element method), the numerical model generation is time consuming often limiting the user to try a variety of other possible design alternates. The process might be lengthy and difficult as it involves a more iteration with different prototypes.

Noise pollution created by engines becomes a vital concern when used in residential areas or areas where noise creates hazard. Generally, noise level of more than 80 dB is injurious for human being. Mufflers have been developed over the last few years based on electro-acoustic analogies and experimental trial and error. Many years ago Stewart used electro – acoustic analogies in deriving the basic theory and design of acoustic filters [1]. Later Davis et al. published results of a systematic study on mufflers [2]. Igarashi and his colleagues calculated the transmission characteristics of mufflers using equivalent electrical circuits [3-4]. Parrot later published results for the certain basic elements such as area expansions and contractions. Sreenath and Dr. Munjal gave expression for the attenuation of mufflers using the transfer matrix approach [5]. The expression they developed was based on the velocity ration concept. Later, Dr. Mujal modified this approach to include the convective effects due to flow [6]. Young and Crocker used the finite element method to predict four-pole parameters and then the transmission loss of complex shaped mufflers for the case of no flow [7].

Ying-change, Long-Jyi used optimized approach of maximal STL and muffler dimension under space constraints throughout the graphic analysis as well as computer aided numerical assessment [8]. Middelburg, J.M. and Barber T.J. present different configurations of simple expansion chamber mufflers, including extended inlet or outlet pipes and baffles have been modelled numerically using CFD in order to determine their acoustic response [9]. However, most of the research studies based on formulation of mathematical equation and trial and error method.

Most recently, automotive engineers have been experimenting with electronic noise suppression muffler. A sound pressure wave, 180 degree out of phase, is generated by an electronic device to cancel out a similar sound wave generated by the engine. It is an effective way of cancelling noise without restricting the flow. Unfortunately, it is too costly and currently impractical for most of today’s engines. However, out of phase sound wave cancellation is the best technology so far to control engine noise. Now-a-days, this 180 degree phase sound is created within the engine muffler by reflecting the out-going sound waves. This reflected sound is used to attenuate the main noise. This procedure is called reflective noise cancellation system. Using a resonator sometimes does this.

II. ENGINE NOISE

Pulses released by the exhaust are the cause of engine noise. When the expansion stroke of the engine comes near the end, the outlet valve opens and the remaining pressure in the cylinder discharges exhaust gases as a pulse into the exhaust system. These pulses are between 0.1 and 0.4 atmospheres in amplitude, with pulse duration between 2 and 5 milliseconds. The frequency spectrum is directly correlated with the pulse duration. The cut-off frequency lies between 200 and 500 Hz. Generally, engines produce noise of 100 to 130 dB depending on the size and the type of the engine.[10]

III. MUFFLER DESIGN PROCEDURE

The various types of mufflers used in automobiles are
1. Baffle type
2. Resonance type
3. Wave cancellation type
4. Combined resonance and absorber type
5. Absorber type mufflers.

Two typical reactive muffler designs are shown in Figure 1 and Figure 2. The first design, shown in Figure 1, is frequently chosen because of its low cost and because it causes a lower back pressure.
The second design, shown in Figure 2, provides more attenuation and is typical of the design recommended by muffler manufacturers. However there is no direction connection between the inlet and the outlet so back pressure is generated that can effect engine performance. This is sometimes referred to as a baffled muffler design.

From an acoustic standpoint the muffler shown in Figure 1 has multiple cavities that are connected to the exhaust pipe by the holes illustrated on the central tube. When there is flow through the exhaust pipe a vortically flow can be created in each hole connecting the pipe to the cavity and this can have a significant effect on the connectivity between the two, reducing the insertion loss of the muffler. In Figure 2 the design differs in as much that there is no direct path for the exhaust gases to flow through the muffler, the flow speed is reduced and this reduces the vortex shedding that can cause problems in the design shown in Figure 1.

Figure 3 shows the Type 16 muffler. This is a typical resonator muffler designed for automotive applications and expected to have a low frequency attenuation characteristic that targets the noise generated at the engine firing frequency. Note how there are two separate cavities in this design and the inlet and outlet pipes extend into the cavity.
Due to its complexity of design it is not possible to estimate the performance of this muffler from its dimensions alone unless a numerical finite element analysis is carried out and accurate estimates can be made of the flow resistance in the perforations connecting the cavity.

The Type 20 muffler is a cylindrical expansion chamber which is filled with sound absorbing material as shown in Figure 4. This design will have maximum low frequency attenuation at 240 Hz and pass band at around 480 Hz. The sound absorbing material will reduce the impact of the pass band and improve the attenuation at high frequencies, since it will act as a dissipative muffler.

A. PURPOSE OF MUFFLER
Mufflers are installed along the exhaust pipe as a element of the exhaust system of an IC engine to reduce its exhaust noise. Mufflers use neat technology to cancel out the noise. The muffler reduces exhaust noise by dampening the pulsations in the exhaust gases and allowing them to expand slowly. It was usually made of sheet steel, coated with aluminium to reduce corrosion. Some are made of stainless steel.

A muffler contains perforated pipes, baffles and resonance chambers. Many also contain sound-absorbing material such as fibreglass or wire wool. The muffler slows down the gases and breaks up the pulsating sound waves, and so reduces the noise. It must cause as little restriction as possible. Poor design can cause excessive back-pressure that will slow down the escape of the exhaust gases and reduce engine performance. Some mufflers combine baffles and pipes to alter the flow of gases without restricting them. Gases enter through the inlet and must reverse their way of flow before they exit through the outlet. This is called a reverse-flow muffler.

Some mufflers use double outer-skins to diminish heat and noise transmission. Some exhaust systems use a resonator as well as a muffler. It looks like a muffler but it usually has a straight-through design and it contains sound absorbing material. It’s designed to remove types of sound that mufflers can’t remove. Silencers and mufflers cover a wide range of noise decrease devices and must be considered one of the most powerful weapons available to reduce noise emitted from cars, trucks, motor cycles, boats, vacuum pumps, compressors.


The principle of the new muffler is shown in Fig.5. The exhaust gases are introduced in inlet and directed by a cone, flowing into the space between inner and outer pipes, and then distributed automatically, coming into the chambers through the radial rectangular slits using a U-shaped bypass pipe. In each chamber, the coming exhaust gases are divided into two parts which has the same magnitude and 180° phase difference, when these two parts gases are made to gather at centre-line of the chamber, they are cancelled each other, leading that gas flow rate is lowered. Also the expansion chamber in the middle of the muffler helps to reduce the noise further. Since the two openings chambers positioned at each chamber are big rectangular slits and also the gas flow speed is lowered by the cancelling, the pressure loss is much lower when gas goes through the muffler meaning at the backpressure of the muffler is lower.
C. FIVE DESIGN CRITERIA

(1) The acoustic criterion, which specifies the minimum noise reduction, required from the muffler as a function of frequency.

(2) The aerodynamic criterion which specifies the maximum acceptable average pressure drop through the muffler at a given temperature and mass flow.

(3) The geometrical criterion, which specifies the maximum allowable volume and restrictions on shape.

(4) The mechanical criterion, which may specify materials from which it is durable and requires little maintenance.

(5) The economical criterion is vital in the marketplace.

The Muffler Design methodology for the engine involves 8 steps.

**Step 1: BENCHMARKING**

**Step 2: TARGET FREQUENCIES**

Target frequency is required to more focus on transmission loss. For calculating the target frequencies engine max power rpm is required and calculation follows,

Hypothetical Computation:

The exhaust tones are calculated using the following

Formulae:

\[
\text{Cylinder Firing Rate (CFR)} = \frac{\text{Engine Speed in RPM}}{60} \quad \text{(two stroke engine)}
\]

\[
= \frac{\text{Engine Speed in RPM}}{120} \quad \text{(four-stroke engine)}
\]

Engine firing rate (EFR) \( = n \times (\text{CFR}) \),

Where \( n \) = no. of cylinders

**Step 3: MUFFLER VOLUME CALCULATION Swept volume**

\[
V_s = \frac{\pi D^2 L}{4}
\]

Where, \( D \) = diameter of cylinder

\( L \) = stroke length

Total swept volume \( = n \times V_s \)

Volume to be consider for calculation =

\[
V = V_s \times \text{Factor}
\]

Silencer Volume: Volume of silencer must be factor of at least 12 to 25 times the volume considered. Volume can be adjusted depending on the space constraint.

Silencer Volume = Factor \( X \) Consider Volume

**Step 4: INTERNAL CONFIGURATION AND CONCEPT DESIGN**
Based on the benchmarking transmission loss and the target frequencies, designer draws few concepts of internal configuration that meets the packaging dimension within the volume.

Every concept and internal arrangement is then formulated to the best possible configuration so as to achieve best acoustic performance and best backpressure.

**Step 5: VIRTUAL SIMULATION**

Based on above mentioned approach, different concepts will be arrived with optimum combinations of different elements inside volume of the silencer. Finalised concepts will be verified virtually using CAE simulation software’s towards the achievement of transmission loss and back pressure.

**Step 6: PROTOTYPE MANUFACTURING**

All the above stages combined with the packaging of the engine evolve the design of the prototype muffler and these can be taken up for manufacturing.

**Step 7: EXPERIMENTAL TESTING**

The experimental determination of back pressure on engine and transmission loss on two source method for different concepts of confirmed. The prototypes of all concepts that are made at the above step are tested for the transmission loss to verify the target value.

**Step 8: DESIGN FAILURE MODE AND EFFECT ANALYSIS**

IV. CONCLUSIONS

This paper emphasizes the importance of the design process. Designer will easily design effective muffler through follow above step. This approach serves the purpose of reducing the number of iterations, product development time and cost with better design.

Although the practical approach has become an important tool in making muffler design more of art than science, the need for design verification will always be necessary at end of each step.

REFERENCES