Development of An Absorption Silencer for Generator's Noise Reducing

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Abstract—Noise pollution is considered to be one of the major environment pollutants which affect human beings both physically and psychologically, as such, a noise-free environment is in great demand worldwide. Diesel engine generators are highly appreciated as power sources of electric equipment in factories, houses and business centers. Loud sounds from diesel generators are a major cause of noise pollution. This paper analyzes the noise source of diesel generators and mitigates this pollution by a modified absorbance silencer or muffler. For automotive engines, the principle source of noise is its intake, radiator, combustion, etc. In our society, all of the industries, the residential sector and business plants use generators. In this research, an absorbance silencer is modified for reduced noise of the generator set. It is constructed from a combination of baffle or perforated duct with sheet metal. This paper aims to study the sound characteristics of generator sets and also aims to reduce the sound by means of a well-modified muffle silencer. This paper focuses on design and tests silencers, particularly absorption silencers for engine exhausts.

Keywords: Diesel Engine; Generator; Absorption Silencer; Noise.

I. INTRODUCTION

Sound pollution means unwanted sounds or noise. It is perceived by most people as annoying. Noise pollution harms most people’s lives. Additionally, it is a great cause of environmental pollution. It greatly hampers humans not only physically, but mentally also. For these reasons, noise reduction is in great demand in this society, and noise prevention is a rising concern in all markets. In our society, all of the industries, the residential sector and business plants use generators. Diesel engine generators cause loud sounds. A silencer is essential and an important part for sound attenuation of engine exhausts. There are many theories and designs of acoustic silencers of generator sets, developed in detail by Stewart theory and design of Acoustic and silencer of Generator set developed in detail by Stewart [1, 2] and he apply it to create many types of silencer and also success that explained in[2]. In 2013 Dr. Chazot, Nenning and Perry performed the method of unity finite element of 2D noise field with sound absorbing materials [3]. Now a days Ontop is a large company who designing, producing and manufacturing prefab modular flue and also distributing. It disposes of a modern product that certified ISO 9001 and also environment friendly as metaloterm lightweight silencer for flue system. In 2012, Mr. Ghosh, Bose and Chakraborty in India modified muffler and get a good performance of a diesel engine by used it [4]. The review of Generator set and silencer should be not complete without it mixed the effects of different absorption elements [5]. The diesel engine is the main noise source of sound power also the generator exhaust and radiator fan [6], are measured by the method of sound intensity. At first May and Olson expressed an electronic noise absorber by pressure release on back face of resistive sheet [5]. Its introduce the notion of active absorption. Guicking and Lorenz in the year of 1980 fulfilled this theory and done experiment [7]. Various research have sought to complement multiple hybrid absorbance technique, leading to patent application [8]. In 1997 Mr. nail and Furstoss improved a layer of optical wool backed by air cavity closed through an active surface [9] by an active treatment. In the same year Beyene and Burdisso found active boundary condition [10]. They achieved it by impedance adaption means in layer of porous rear face. But after the century in 2004 cobo et al. explained structure of thinner hybrid active and passive absorbers feasibility. He used micro perforated panels more than the porous materials[11]. The design mufflers and procedures are also in the literature (Munjal, 1987)[12]. Long time ago Stewart used electro acoustic analogies in deriving acoustic filters theory & design.[1] After that Davis approach systematic studies result of muffler,[13]. Igarashi and M. Toyama calculated transmission characteristics by using electric circuit. [14, 15]. The last year in 2014 Babu, A.R Rao simulated a new muffler for reduce sound level of SI engine.[16] In this paper, an absorbance silencer is modified for reduced noise of a generator set. It is constructed using a combination of baffle or perforated duct with sheet metal. The maximum generator has a simple silencer for reduction of the exhaust noise only.
Noise means unwanted sounds that are abnormal or loud- it is a relative term. Singing or hearing a song or musical instruments may be noise for some. Automotive engines create a large portion of the noise in our society. I.C engines are also a great source of sound pollution, as they are a powerful source of noise. The noise sources of both gasoline and diesel engines are the same, but their noise characteristics are different. Noise is highly subjective, and that which is irritating to one can be acceptable for another. To overcome this, noise is measured by a decibel (dB) meter in unit of dBs, withdB(A) representing the human ear’s sensitivity of 0 to 180 dB, where 0dB means no sound at all, and 180dB is a loud sound. An alternative explanation for 180 dB is the level of sound an atomic bomb would make upon explosion. The dB scale is a logarithmic meter. If dBs rise in increments of 10, then the sound level rises 10 decade or 10 fold. If we know the level of noise source and maximum allowed level, then it is easy to calculate the required sound reduction for the silencer. The USA standard ASTM E413 describes frequencies of machinery as being in the range of 125 to 4000 Hz [17]. Similarly, The international standard ISO 717 refers to frequencies 100 to 3150 Hz[18]. The SI unit of sound reduction is dB and frequency is Hz[19].

II TECHNIQUES

The noise reduction techniques are dependent on the generator room, exhaust and its type of structure, borne, noise & vibration. Some techniques are shown in the following-

A. Generator Rooms:
   a. Room Enclosure:
      i. Roof
      ii. Walls
      iii. Doors
      iv. Internal Lining
   b. Intake Air and Discharge Air:
      i. Duct Silencers
      ii. Acoustic Louvers
   iii. Exterior Screens

B. Exhaust Noise:
   a. Resistive Mufflers/ Absorbance Silencer
   b. Active Noise Control

C. Structure Borne Noise & Vibration:
   a. Spring isolators on generators larger than 175kW.
   b. If a floor joint is present, the weight of concrete beneath the generator should be not less than twice the generator weight.
   c. Flexible pipe connectors, duct connectors, electrical connection at the generator.

Active noise cancellation silencers used to be available as a manufactured product, but are not currently available. They were effective in reducing the low frequency tones associated with the cylinder firing. In this research paper, we design and modified resistive mufflers / absorbance silencers for reduction of exhaust noise.

III METHODOLOGY

The methodology involves silencer design and development, and consists of some steps. After this, a modified silencer for use with a generator for a practical experiment is produced. The properly designed muffler for any particular application should satisfy the often – conflicting demands of at least five criteria simultaneously.

A. Criterion and Flowchart of Methodology: The acoustic criterion, which specifies the minimum noise reduction, is required from the muffler as a function of frequency. The operating conditions must be known because large steady-flow velocities or large alternating velocities (high sound pressure levels) may alter its acoustic performance. The aerodynamic criterion specifies the maximum acceptable average pressure drop through the muffler at a given temperature and mass flow. The geometrical criterion specifies the maximum allowable volume and restrictions on shape. The mechanical criterion may specify materials that are durable and require little maintenance. The economical criterion is vital in the marketplace [33].
Figure & Step 1 to 6. The steps showing the process of design of the silencer and the experimental setup of the generator set with a diesel engine.

1. Diesel Engine
2. Filter
3. Tank
4. Burret
5. RPM Indicator
6. Clutch or Shaft
7. Exhaust Outlet
8. Alternator
9. Radiator
10. Silencer
11. Sound Meter

The generator block diagram is replaced by the experimental setup block diagram. The various types of generator sets include 150KW, 350KW, 500KW, 1MW and 2MW diesel engines for use during the experiment and data collection. The experimental silencer was designed for a 500KW diesel engine generator set, and the basic specifications of the generator set are given in Table 1.

Table 1. Specifications of the generator set.

<table>
<thead>
<tr>
<th>SN</th>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rating</td>
<td>635KVA</td>
</tr>
<tr>
<td>2</td>
<td>Power</td>
<td>508KW</td>
</tr>
<tr>
<td>3</td>
<td>Current</td>
<td>850A</td>
</tr>
<tr>
<td>4</td>
<td>Rated revolution</td>
<td>1800RPM</td>
</tr>
<tr>
<td>5</td>
<td>Pressure</td>
<td>460KPA</td>
</tr>
<tr>
<td>6</td>
<td>cylinder</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>Cycle/stroke</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Engine Load</td>
<td>75% and Full Load also</td>
</tr>
</tbody>
</table>

**B. Experimental Evaluation of Unsilenced exhaust Noise**

The noise of an engine exhaust varies significantly with its loading. At the full load, the sound level is about 10 dB more than the no-load condition. The silenced exhaust noise level is high at low frequencies. Figure 7 shows a 2MW engine with unsilenced exhaust noise level load for 16cyl at 1800RPM.

![Figure 7. Sound Pressure at 1m distance for 2MW Engine by load.](image)

The graph shows that the exhaust system starts at 110dBA and varies by 10 dBA, reaching a maximum of 120dBA. It is measured 1m from the outlet exhaust. The exhaust sound is affected by turbochargers of engines and after coolers by cooling fans. Hence, collecting noise data from engines is the optimal method chosen for this experiment. The unsilenced engine’s exhaust noise level is high at low frequency. Figure 8 shows data comparisons for the various engines including 150KW, 350KW, 500KW and 2 MW diesel engines.

![Figure 8. Sound Pressure of various Engine at 1m distance.](image)

The spectrum of exhaust noise always contains loud sound associated with the cylinder firing rate (CFR). Each cylinder fires once every drive shaft revolution in a 4-cycle engine, and the CFR is calculated with different formulas for 4 cycle engines (Equation (1)), and 2 cycle engines (Equation (2)).

\[ CFR = \frac{RPM}{120} \]  

(1)

\[ CFR = \frac{RPM}{60} \]  

(2)

The engine firing rate is defined as

\[ EFR = N \times CFR \]  

(3)

Where, \( N \) = number of cylinders.
Figure 9 shows the exhaust noise of a 500 KW diesel engine with 6 cylinders, running at 1800RPM without using any silencers. The narrow band spectrum data was collected at a 3m distance from the outlet of the exhaust without use of a silencer, with the engine running at full load. The engine firing rate (EFR) is 90Hz and the CFR is 15 Hz.\[21\]

Figure 9. Sound Pressure Level of CFR & EFR without silencer

IV DESIGN & PRINCIPLES

The first step in any design and development activity is to set a target by doing a benchmarking exercise of models, which was carried out in this experiment.

A. Benchmarking:

After the benchmarking exercise, one needs to calculate the target frequencies to give more concentration of higher transmission loss. The primary step in silencer design is benchmarking based on engine input data:

\[ P = 80 \quad \text{litres} \]

\[ \text{ Maharashtra} = 98 \quad \text{litres} \]

\[ \text{ Engine firing rate (EFR)} = 90Hz \]

\[ \text{ CFR} = 15 \quad \text{Hz} \]

Engine Firing rate (using Equation (3)): \( 6 \times 1.5 = 90Hz \)

C. Volume of the muffler (Vm):

The volume of the muffler is defined as Vm, with units in litres. The calculation of the volume can be done using Equation (4):

\[ Vm = Vf \times \frac{\pi}{4} (d^2 \times l) \times \left( \frac{\text{number}}{2} \right) \]

Swept volume per cylinder is calculated as follows:

\[ Vs = \frac{\pi}{4} (d^2 \times l) = \frac{3.14 \times 80^2 \times 90}{4} = 0.5 \text{ Lit.} \]

Total \( n \times V_s = 6 \times 0.5 = 3 \text{ Lit.} \)

\[ Volume, V_m = (n) \times \frac{Vs}{2} = 1.5 \text{ Lit.} \]

The silencer volume is considered to be at least 12 to 25 times larger, with a factor of 16

**Silencer Volume = 16 \times 1.5 = 24 \text{ Lit.}**

D. Insertion Loss:

Figure 10 shows insertion loss for various mufflers, showing the absorptive muffler performance being optimal in the frequency region of 1000Hz to 2000Hz.

The 500 KW generator engines have an unsilenced exhaust noise level (UNL) of 116 dBA at a 1 m distance. A safety factor (SF) of 5 dBA is allowed for noise transmission paths. The Exhaust noise criteria (ENC) = Required Noise Criteria (RNC) -5 dBA. This means that if our expected noise level is 60dBA, then we have to design a muffler for 55dBa. The UNL equation from the exact location is shown in Equation (6):

\[ Lp(xr) = Lp(x0) - 20 \log \left( \frac{xr}{x0} \right) \]

For example, \( Lp(25 \text{ m}) = Lp(1 \text{ m}) - 20 \log \left( \frac{25}{1} \right) \)

\[ Lp(25 \text{ m}) = 116 - 28 = 88 \text{ dBA} \]

The required insertion loss, \( IL = UNL - ENC + SF \).

\[ IL = 88 \text{ dBA} - 55 \text{ dBA} + 5 = 38 \text{ dBA.} \]

A silencer element’s transfer matrix method (TMM) is a function of state variables [28], geometry of elements, velocity of mean flow, duct liner properties [29]. The transfer matrix method also influenced by temperature, nonlinear effects, high order mode etc.[30]. The Transmission Loss is shown in Equation (7) below.[24, 31, 32]

\[ TL = 20 \log \left[ \frac{1}{2} \left( \frac{\tau_{11} + \tau_{12} + \tau_{13} + \tau_{14}}{\tau_{11} + \tau_{12} + \tau_{13} + \tau_{14}} \right) \right] \]

E. Internal Configuration and Design of the Proposed Silencer:

The silencer contains glass wool shielded from the exhaust stream by perforated metal. Glass silk, fiber optic or steel wool
is commonly used. When the absorbance silencer works effectively, the materials suffer from deterioration in service. The combustion products take the form of absorbing materials. Materials melt due to heat generation until they have low thermal conductivity. The absorbance silencer is designed with low pass filter forms in order for it to be able to deal with the low frequency. Effective measures were used to reduce the sound. The noise power has to be applied in the numerical analysis.

The operation and principle of the new absorption silencer is shown in Figure 11. Exhaust gas enters from the inlet pipe and is directed in multiple directions in the indoor chamber. The indoor space has a U-shape configuration with large spaces. Therefore the gases flowing into the space from the inlet to the outlet are distributed by the inner pipe hole. The inner pipe also has absorption materials like glass fiber, steel wool and sheet hole. The exhaust gases are absorbed automatically by these materials as they move around the inner space. The flow of these gases interfere with the leading gas flow, causing it to have a lower speed [23]. Figure 12 shows the inlet pipe and tail pipes (outlet pipes) with a diameter of 8 inches. The main perforated chamber is 6 feet long with a 28 inch diameter. The absorption materials on the coating layer are only 2 inches wide. The exhaust outlet pipe has resonance that increases its noise. To remove this, a short tail was used with a length of a quarter wavelength(\(\lambda/4\)). Equation (8) describes the size of the tail pipe that described by jerry j lilly in AGL acoustic [17].

\[
\text{Resonance frequency of Tail pipe}, \\
f_n = nc/(2L) \\
c = \text{sound speed}. \text{For a four stroke engine the EFR frequency is 90Hz and its wavelength is 20ft. The best tail pipe is exactly 5 ft. for cancel the EFR frequency of 90 Hz tone at the exhaust of outlet [21]. Here give the calculation for 6 cylinders @ 1800 RPM (950°F)}
\]

\[
CFR = \frac{1800}{120} = 15 \text{Hz} \\
EFR = 6CFR = 90 \text{Hz} \\
c = 49.03 * \sqrt{(460 + 950)} = 1841 \text{ ft/sec} \\
\lambda_{CFR} = \frac{1841}{15} = 122 \text{ ft.} \\
\lambda_{EFR} = \frac{1841}{90} = 20 \text{ ft.} \\
L = \frac{20}{4} = 5 \text{ ft.}
\]

Where \(L\) = tail pipe length. The tail pipe is a metal sheet that lies downstream of the exhaust silencer and has an acoustic resonance that can increase or amplify the final exhaust noise if matched. This resonance can be removed by making the tail half of the wavelength at the tone or sound frequency. However, it is advisable to avoid the tone by creating an accurate size at a quarter of the wavelength. The pipe hole’s or perforated holes’ number and diameter with measurements are given in Figure 13 [24].

Here \(n\) = positive integer number. when \(L = n \lambda/2\), then occurs Resonance and for this reason this size is avoided.
The pipe hole of expansion chamber of the inner space helps to reduce the sound. The inlet pipe and outlet pipe can be extended to get more attenuation [25, 26]. The absorption materials also reduce higher frequencies, especially that of mineral wool or glass wool [27].

\[
V_m = \frac{\pi}{4} (d^2 \times l)
\]

\[ D^2 = 0.04 \]

\[ D = 0.2m = 200\text{mm} \]

And the perforated hole diameter is, \[ d = \frac{1.29}{\sqrt{N}} \] [22]

V RESULTS

The silencer design is successful as it reduced the overall noise to the lowest level that can be reached within acceptable limits. It is of good quality and does not have any effect on engine performance. The noise or sound attenuation characteristics of the new absorption silencer was measured and also compared with the old silencer and is presented in Table 2. Shao (2011) measured and tested a new muffler and compared it with traditional muffler. The new muffler was designed with a combination of absorbance materials, a perforated pipe, an expansion chamber, a baffle and interpole ducting [23]. Figure 16 shows the test result.

<table>
<thead>
<tr>
<th>SN</th>
<th>DISTANCE FROM SILENCER</th>
<th>PREVIOUS RECORD dBA</th>
<th>AFTER RECORD dBA</th>
<th>GENERATOR LOAD</th>
<th>PREVIOUS TEMP °C</th>
<th>AFTER TEMP °C</th>
<th>KPA</th>
<th>RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>1 Meter</td>
<td>120 dBA</td>
<td>85 dBA</td>
<td>75 %</td>
<td>82°C</td>
<td>82°C</td>
<td>460</td>
<td>1800</td>
</tr>
<tr>
<td>02</td>
<td>2 Meter</td>
<td>109 dBA</td>
<td>80 dBA</td>
<td>75 %</td>
<td>82°C</td>
<td>82°C</td>
<td>460</td>
<td>1800</td>
</tr>
<tr>
<td>03</td>
<td>3 Meter</td>
<td>106 dBA</td>
<td>70 dBA</td>
<td>75 %</td>
<td>82°C</td>
<td>82°C</td>
<td>460</td>
<td>1800</td>
</tr>
</tbody>
</table>

Figure 16 shows that the sound pressure level decreases by approximately 30 dB with a modified absorption silencer as compared to a traditional silencer. It also gives a better performance at various distances from the outlet exhaust as compared to other silencers. At 1500 RPM, the modified silencer gives the best result without any change of engine parameters - for example the temperature, pressure and KPA is the same as other traditional silencers. Figures 17 - 19 show the level of sound pressure of an exhaust in three types of silencers. Table 2 and Figures 17 - 19 illustrate that the modified absorption silencer has better noise reduction properties than other, traditional silencers and mufflers. Figure 20 shows a narrow band spectrum data, collected from a 3 m distance from the outlet of an exhaust, used with a proposed silencer. Note the dip in the curve in the vicinity of 80 Hz and 240 Hz. The fact that there is no EFR tone (240 Hz) at all is very impressive. The main benefit of the modified absorption silencer is the reduction of exhaust noise. However, there are also some other advantages that are highly beneficial, such as: the reduction of noise; possession of a twin wall; the property of being pre-insulated, light and portable; the property of being of a
minimal length and weight; possessing an inlet and an outlet that suit modular character; being light weight; having low vibration ability; being easy to build and inexpensive - complex equipment and mounting kits are not needed. In the market, the financial criterion is of crucial importance.[14, 33]. In addition, the modified silencer is easily designed and re-assembled.

![Figure 17. Time domain chart and spectrum of new absorption silencer](image1)

![Figure 18. Time domain chart and spectrum of local or traditional silencer](image2)

![Figure 19. Time domain chart and spectrum of without silencer](image3)

![Figure 20. Sound Pressure Level of CFR & EFR with Proposed silencer](image4)

**VI CONCLUSION**

The experiment was performed successfully with good conditions. All the spectrums have been observed, in addition to the rules concerning its modification. This paper proposed a practical approach and the importance of a methodology to create a modified exhaust silencer. This design methodology gave a clear basic concept and will help anyone. It saves production time and cost with the easy and simple design. The experiment’s conditions and the testing method are correct but the silencer was only tested with a 500KW generator set which ran at 1800RPM. It usually causes reduction of exhaust gas flow noise. Further work has to be done to test this absorption silencer with various generator sets such as 1 MW and 2MW engines. Additionally, the inclusion of transmission loss was included by using the TMM. It will be developed with the frequency range in the future in order to give a reliable expected value.