

Analysis of Exhaust System- ‘Semi Active Muffler’

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ABSTRACT: Main drawback of I.C. engines working is that it is a major source of noise pollution. That is why the reduction of exhaust noise generated from engine is in today's world an important issue. Attaching a muffler in the exhaust pipe is the good option for reducing noise. But muffler requires specific design and construction considering various noise parameters produced by the engine. Since early development of mufflers, the main objective of design was attenuation of sound in regular mufflers. Which causes a great amount of back pressure at the exhaust port thus losing power, increasing fuel consumption and piston effort to exhale the gases out. For high performance engines the free flow exhaust is made in which the sound level is not important but zero or less back pressure is. There is no intermediate muffler type in between both these, so semi active muffler is an step between these two, in which it attenuates sound when engine is running at low rpm, and converts in free flow when engine at higher revs.

KEYWORDS: CFR-cylinder firing ratio, EFR-engine firing ratio, Semi active muffler, Vm-volume of muffler.

I. INTRODUCTION

Noise pollution is the main issue related to the I.C. engines. These engines are used for various working such as, in power plants, automobiles, locomotive engines, and in various manufacturing industries. Noise pollution created by engines becomes a main issue when used in residential areas or areas where noise creates harmful effects. Generally, noise level of greater than 80 dB is harmful for human being. The main sources of noise in an engine are the exhaust noise and the noise generated due to friction between various parts of the engine. The exhaust noise is the most dominant. To reduce this noise, various kind of mufflers are generally used. The level of exhaust noise reduction depends upon the type and manufacturing and working of mufflers. Mufflers are used by the engine makers for more than 100 years. As the name indicates, the important function of the muffler is to reduce or muffle the noise emitted by the internal combustion engine. Muffler technology and its function has not get developed very much over the past 100 years. The exhaust gases are allowed to flow through a number of chambers in reactive type mufflers or straight through a perforated pipe wrapped with sound absorbing and helps to decrease sound level such type material in an absorptive type muffler. Both types have good points and some weaknesses too. The reactive type muffler has functional work of restrictive sound and prevents even the good engine sounds generated in working condition from coming through, but complete the main function of reducing noise. On the other side, most absorptive type mufflers are less restrictive, but allow too much engine noise generated at the time of working to come through it. In presence of the packing material, absorptive type mufflers tend to create more noise with age. Currently, automotive engineers have been experimenting with electronic noise suppression muffler. A sound pressure wave which is 180 degree out of phase is created by an electronic device to cancel out a similar sound wave created by the engine. It is a major functional way of cancelling noise without restricting the flow. But main issue is that it is too costly and currently in research for used in most of today's engines. However, out of phase sound wave cancellation technology muffler is the best technology so far to control engine noise. Currently, this 180 degree phase sound is created inside the engine muffler by reflecting the sound waves generated by exhaust gases. This reflected sound is used to attenuate the main noise. This working of muffler system is called reflective noise cancellation system. With the help of a resonator sometimes does this.^[1]

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II. LITERATURE SURVEY

Internal combustion engines are typically supported with an exhaust muffler to decrease the acoustic pulse generated by the combustion working. A high intensity pressure wave produced by combustion in the engine cylinder travel through the exhaust pipe and radiates from the exhaust pipe outlet. The pulse repeats at the firing frequency of the engine which is defined by $f = (\text{rpm of the engine} \times \text{number of cylinders}) / 120$ for the working of a four stroke engine. The frequency content of exhaust noise is canceled by a pulse at the firing frequency of engine, but it also has a broadband component to its spectrum when it reaches to a higher frequencies. By measuring the pressure pulse of exhaust pipe line on a Continental O-200 engine show that the major part of the pulse energy located in the frequency range of 0-600 Hz. Exhaust mufflers are designed to decrease sound levels at these frequencies level.^[3]

A. ENGINE NOISE

Pulses generated from the exhaust is the factor to cause of engine noise. When the expansion stroke of the engine comes near the end, the outlet valve tends to open and the remaining pressure from the cylinder discharges exhaust gases as a pulse into the exhaust system. These pulses have range between 0.1 and 0.4 atmosphere in amplitude as well as having pulse duration between 2 and 5 milliseconds. The frequency spectrum is relate directly with the pulse duration. The cut-off frequency having range between 200 and 500 Hz. In general, engines make noise of 100 to 130 dB depending on the size as well as the type of the engine^[1]

B. MAIN COMPONENTS OF THE EXHAUST SYSTEM

1. Exhaust manifolds
2. Catalytic converters
3. Mufflers
4. Resonator
5. Tail Pipe

C. TYPES OF MUFFLERS

1. Reactive muffler
2. Absorptive muffler
3. Combination of absorptive and reactive muffler.

These three mufflers are mainly used in the construction equipment's.

1. REACTIVE MUFFLER (or) SILENCER

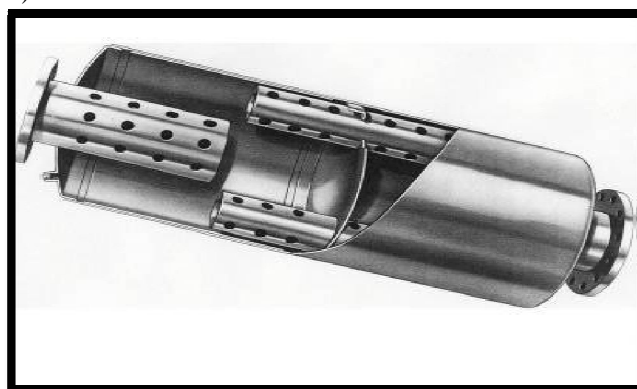


Fig.1 REACTIVE MUFFLER (or) SILENCER

In this the reactive type muffler can be used in the construction equipment's. Reactive silencers generally having many pipe segments that internally connected with a number of larger chambers. The noise reduction mechanism of reactive silencer is that the area discontinuity provides an mechanism of cancellation for the sound wave traveling through the pipe. This cancellation results in a reflection of part of the sound wave back toward the source or moving in backward

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or forward through the chambers. The reflective effect generated in the silencer chambers and piping (typically referred to as resonators) in some time interval prevents some sound wave elements from being transmitted past the silencer. The reactive silencers are having higher efficiency at lower frequencies compare to high frequencies, and generally used in wide range to attenuate the exhaust noise of internal combustion engines.^[3]

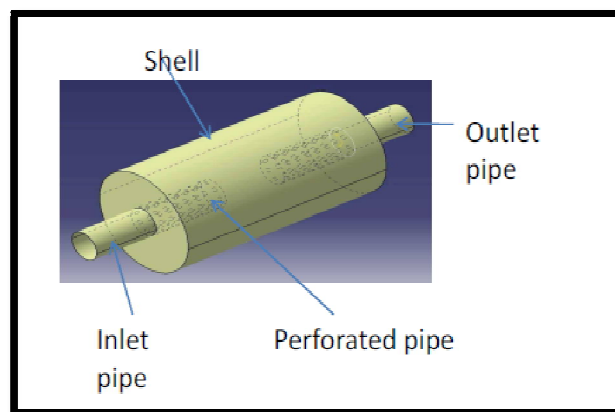


Fig 2. Components of Reactive Muffler Exhaust System

At the time of working exhaust gases from inlet pipe pass through the perforations present inside the shell, the gases get spread in so many directions. Those reflected gases from the inside surface of the shell, the sound cancellation process of waves occurs is occurred. The gases travel through the perforations in so many times and even get reflected from the shell surface. By all the effect of these, the level of sound at the muffler outlet is decreases rapidly. The flow through the muffler and changes the various components such as velocity and pressure through the length of the model can be accurately demonstrated with the help of computational fluid dynamics analysis which gives accurate results with short period of time.^[3]

Details of Components:

a) Perforated Pipe:

Discharge the hot exhaust gases along the Perforated tubes are mainly used in the muffler to perforation holes present in the tube. Calculations for the hole diameter and the number of perforations as per the muffler volume and requirement of the system. The perforation have to be maintain proper distance between the each hole for better performance of the system. Here perforations are closed with the manufacturing of surfaces and it should be placed in separate collector. After simple geometry of system, perforation surfaces are to be meshed with shell elements with less element length to have greater number of nodes on the surface to achieve proper flow of gases and minimize noise level.

b) Baffle Plate:

Baffle plates used in many applications having different designs. However, If baffles designed to work in pressurized conditions required to follow systems design for proper distribution function, and to maintain flow rate throughout our system. In the system many baffles are adjustable and some are fixed. Air noise is part of that baffles are used to help decrease the back pressure during the hot gas from exhaust passing through the muffler. In system perforated baffles are mainly used to expand the exhaust gases from one room to another room with the help of their perforations. Perforated and non-perforated baffle plates are combined together with muffler shell with the help of trim operation. Main side effect by using muffler is pressure drop or back pressure which is unavoidable.

c) Back Pressure:

Backpressure usually refers to the pressure exerted on a moving fluid by obstructions against its direction of flow. The word back may suggest a pressure that is exerted on a fluid against its direction of flow indeed, but there are two reasons to object. First, pressure is a scalar quantity, not a vector quantity, and has no direction. Second, the flow of gas

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is driven by pressure gradient with the only possible direction of flow being that from a higher to a lower pressure. Gas cannot flow against increasing pressure. It is the engine that pumps the gas by compressing it to a sufficiently high pressure to overcome the flow obstructions in the exhaust system.^[2]

D. EFFECTS OF INCREASED BACK PRESSURE:

At continuously increasing back pressure levels, the engine has to compress the exhaust gases to a higher pressure which requires additional mechanical work and/or less energy gained by the exhaust turbine which can affect intake manifold boost pressure. This leads to an increase in fuel consumption, PM and CO emissions and exhaust temperature. The increased exhaust temperature can lead to overheating of exhaust valves and the turbine. An increase in nitrogen oxide emissions is also possible because of increase in engine load. Increased back pressure affects performance of the turbocharger, results in changes in the air to-fuel ratio which increases which may be a main cause of emissions and engine performance problems. The magnitude caused due to effect depends on the type of the charge air systems. Increased exhaust pressure helps to prevent some exhaust gases from leaving the cylinder (especially in naturally aspirated engines), with the help of an internal exhaust gas re-circulation system which is responsible for some nitrogen oxide reduction. Small amount of nitrogen oxide reductions reported with some diesel particulate filters system, usually in the range to 2-3% percent, are possibly resulted by this effect. More amount of exhaust pressures can increase the chances of failure of turbocharger seals of engine, which may result in oil leak agent the exhaust system. In systems with catalytic diesel particulate filters or other catalysts used in the engine, such oil leak can also result in the catalyst deactivation by phosphorus and other catalyst poisons present in the oil. Maximum engines have maximum allowable engine back pressure specified by the manufacturer of the engine. If the engine is used at higher speed and creates more back pressure might invalidate the warranty of particular engine. Those standards generally accepted by automotive engineers that for every inch of Hg of back pressure (Mercury inches of Hg is a unit used for measuring pressure) nearly 1-2 HP of power lost depending on the displacement and efficiency of the engine, as well as the combustion chamber design etc.

ENGINE SIZE	BACK PRESSURE LIMIT
Less than 50 kW	40kPa
50-500kW	20kPa
500kW and Above	10kPa

Table.1 VERT Maximum Recommended Exhaust Back Pressure

E. BASIC THEORY:

Invention of the internal combustion engine is mainly happen in nineteenth century, the noise generated by it has been a main source of harmful effects to the environment. Significantly, the exhaust noise if expressed in terms of pressure is about 10 times compared to all other noises (structural noise) combined. So the problems of reducing engine noise mainly include, in sudden decrease in factors of exhaust noise. The design of mufflers has been a point of interest for many years and hence a beneficial deal of understanding has been gained. Most of the research and advances in the theory of acoustic filters research and exhaust mufflers are modified about in the time period of last four decades. Hence good design of the muffler results into give the higher noise reduction and gives required back pressure for the engine. For a given internal standard configuration mufflers have to work for a broad range of engine speed^[3]

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III. DESIGN PRINCIPLE OF MUFFLER EXHAUST SYSTEM

1.Design Principle:

In general, sound waves propagating along a pipe can be attenuated using either a dissipative or a reactive muffler. A dissipative muffler uses sound absorbing material to take energy out of the acoustic motion in the wave, as it propagates through the muffler. Reactive silencers, which are commonly used in automotive applications, reflect the sound waves back towards the source and prevent sound from being transmitted along the pipe. Reactive silencer design is based either on the principle of a Helmholtz resonator or an expansion chamber, and requires the use of acoustic transmission line theory. In a Helmholtz resonator design a cavity is attached to the exhaust pipe. At a specific frequency the cavity will resonate and the waves in the exhaust pipe are reflected back towards the source. However there are also pass band frequencies where the resonator has no effect and so resonator muffler design is targeted to specific frequencies where the majority of the attenuation is required. In some designs, the muffler has several resonators of different sizes to target a range of frequencies. Expansion chamber mufflers reflect waves by introducing a sudden change in cross sectional area in the pipe. They do not have the high attenuation of the Helmholtz resonator, but have a broadband frequency characteristic, with pass bands when half the acoustic wavelength equals the cavity length. Their performance also deteriorates at higher frequencies when the cross axis dimension of the muffler is 82% of the acoustic wavelength (Davis, Stokes, Moore and Stevens). Some expansion chamber muffler systems are also packed with sound absorbing material which helps to improve the high frequency attenuation. In all muffler designs the tailpipe length can have an important effect. The tailpipe itself acts as a resonant cavity that couples with the muffler cavity. The attenuation characteristics of a muffler are modified if the design tailpipe is not used. Also, the effect of exhaust gas flow speed has a detrimental effect on the muffler performance. Beranek gives examples in which the muffler attenuation is reduced from 35 dB to 6-10dB when the flow speed is increased from zero to 230 ft/sec. In typical industrial or diesel truck engine applications the exhaust flow speed can be 164 ft/sec to 390 ft/sec . The effect of flow is related to the interaction of sound with turbulence and will be dependent on the internal design of the muffler.^[5]

2. Design Procedures:

Design procedures for resonator mufflers are given in Beranek and Bies and Hansen , but the process is complex. The procedure is to specify the resonant frequency of the muffler and the desired attenuation. A cavity volume is calculated and then the area of the openings (or connectors) between the exhaust pipe and the cavity must be calculated. Finally a wire or cloth screen to cover the openings must be chosen with the correct flow resistance to provide the correct damping (this reduces the maximum attenuation, but helps to reduce the effect of the pass bands where no insertion loss is achieved). Introducing tailpipes can significantly improve the muffler performance and more detailed consideration of acoustic transmission line theory is required to properly design the tailpipe.

3. Typical Muffler Designs:

Two typical reactive muffler designs are shown in Fig.3 and Fig.4 The first design, shown in Fig.3, is frequently chosen because of its low cost and because it causes a lower back pressure. The second design, shown in Fig.4, 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.

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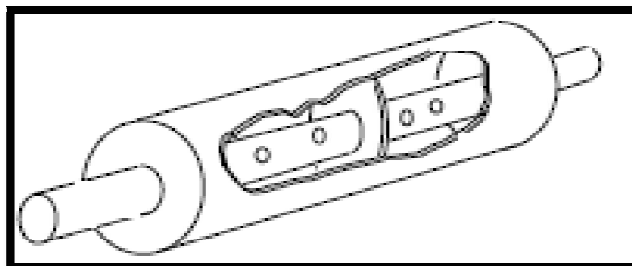


Fig.3 Sketch of a reactive muffler with two cavities and no flow restriction.

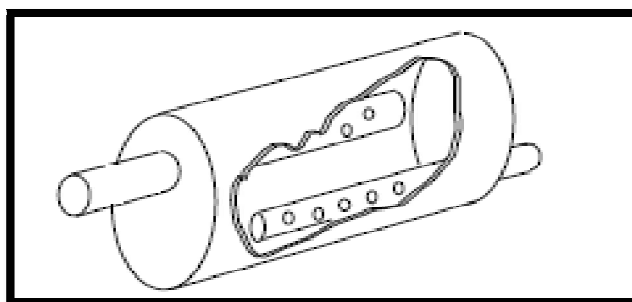


Fig.4 Sketch of a typical automotive reactive muffler in which there is no direct passage between the inlet and the exit.

From an acoustic stand point the muffler shown in Fig.3 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 vertical 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 Fig.4 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 Fig.3. The maximum back pressure allowed for a Continental O-150 or a Lycoming 540 engine is 1 psi. Typical mufflers of the type shown in Fig.3 generate minimal back pressure, while those of the type shown in Fig.4 were measured during this study as having 1.4 ± 0.2 psi of back pressure.

4.Design Calculations:

a.Benchmarking:

The first step in any design is to set a target by doing the benchmarking. The same will be applicable for the silencer here, to set a target in terms of transmission loss.

b. Target Frequencies

After doing benchmarking exercise, there is needs to calculate the target frequencies to give more concentration of higher transmission loss. For calculating the target frequencies engine max power rpm is required and calculation follows,

Theoretical Computation:-

The exhaust tones are calculated using the following Formulae:-

$$\text{CFR} = \text{Engine Speed in RPM}/60.. \text{ For a two stroke engine} \text{-----}(1)$$

$$\text{CFR} = \text{Engine Speed in RPM}/120\text{-For a four-stroke engine} \text{-----}(2)$$

$$\text{EFR} = n \times (\text{CFR}) \text{-----}(3)$$

c.Muffler Volume Calculation Volume Of the muffler (Vm):-

$$V_m = V_f \times [\pi/4(d^2 \times l)] \times (\text{No. of Cylinders}/2) \text{-----}(4)$$

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IV. METHODOLOGY- DESIGN OF AN ORDINARY MUFFLER FOR HERO SPLENDOR

STEP 1: BENCHMARKING

As per design methodology we benchmarked same kind of engine models to set the target of transmission loss of muffler.

Engine data: Hero Honda Splendor

Bore (D) = 50 mm

Stroke (L) = 49.5 mm

No. Cylinders (n) = 1

Engine power (P) = 6.15kw (8.36ps) @ 8000rpm

Max. RPM (N) = 8500 rpm

Allowable back pressure for muffler = Not available (in H₂O)

Transmission Loss Noise target

STEP 2: TARGET FREQUENCIES

(muffler) = 30 dB.

To find fundamental frequency

Cylinder Firing Rate:-

CFR to be calculated as per the equation –2,

CFR = $8000/120 = 66.66$

Engine firing rate

EFR to be calculated as per the equation –3,

EFR = $1 \times 66.66 = 66.66$ Hz

STEP 3: MUFFLER VOLUME CALCULATION

Swept volume (Vs): $(\pi \times d^2 \times L)/4$

= $(3.14 \times 50^2 \times 49.5)/4$

= 97143.75×10^{-6} Lit.

Volume to be consider for calculation,

Volume = (n) x Vs/2 = 0.48

Silencer Volume = Factor x Consider Volume = 2.26485 Lit

Assumed Factor = 4.7083

STEP 4: INTERNAL CONFIGURATION OF MUFFLER AND CONCEPT DESIGN

Diameter of muffler calculated as:

$V_m = (\pi/4) \times d^2 \times L$

$0.00226 \times 10^{-6} = (3.14/4) \times D^2 \times 0.342$

D = 0.091750 m

D = 91.75 mm (Diameter of muffler)

STEP 5: Selection of other parameters

1. 3 chambers for good cancellation capacity
2. Inlet and Outlet extension : Not selected yet
3. Inlet and Outlet extension to be kept 180° reversal.
4. La= Length at which Perforation starts on pipe = Not selected.

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5. Lb= Length at which perforation ends = Not selected.

V. WORKING OF EXHAUST SYSTEM

WORKING OF EXHAUST SYSTEM USING SEMI ACTIVE MUFFLER SILENCER:

Expansion chambers are effective tools for reducing noise in several applications. The most familiar example is probably the automotive muffler, where a single tuned expansion chamber is utilized. Therefore, automotive exhaust system is a significant part of exhaust system. There are several parameters that describe the acoustic performance of a muffler and/or its associated piping. These include the noise reduction (NR), the insertion loss(IL), and the transmission loss (TL). The NR is the sound pressure level difference across the muffler. Though the NR can be easily measured, it is not particularly helpful for muffler design. The IL is the sound pressure level difference at a point, usually outside the system, without and with the muffler present. Though the IL is very useful to industry, it is not so easy to calculate since it depends not only on the muffler geometry itself but also on the source impedance and the radiation impedance. The TL is the difference in the sound power level between the incident wave entering and the transmitted wave exiting the muffler when the muffler termination is anechoic; the TL is a property of the muffler only. The muffler TL may be calculated from models but is difficult to measure. This paper will focus on measuring the muffler TL. In order to select a suitable muffler type, some basic information are necessary regarding how industrial mufflers work. Industrial mufflers, (and mufflers in general), attenuate noise by two fundamentally different methods. The first method, called reactive attenuation - reflects the sound energy back towards the noise source. The second method, absorptive attenuation – absorbs sound by converting sound energy into small amounts of heat. There are three basic industrial muffler types that use these methods to attenuate facility noise – reactive silencers, absorptive silencers and anyone or both of them combined with resonator. The proper selection of a muffler is performed by matching the attenuation characteristics of the muffler to the noise characteristics of the source, while still achieving the allowable muffler power consumption caused by muffler pressure drop. Fortunately, industrial noise sources separate primarily into three different categories with specific characteristics. The first category covers sources that produce mainly low-frequency noise, yet can typically tolerate relatively high-pressure drops. Engines, rotary positive blowers, reciprocating compressors, and rotary screw compressors are types of these sources. It is simply the nature of these machines to produce low-frequency noise and have pressure-volume relationships that are quite tolerant of system pressure drop. These machines are perfectly suited for reactive (chambered) silencers. The second category of noise sources are those that produce mainly high-frequency noise and have performance that is very sensitive to system pressure losses. These sources are almost always moving or compressing a fluid with spinning blades. Examples include centrifugal fans, compressors, and turbines. By definition, this type of equipment is best treated with absorptive silencers for both low and higher temperature applications. Resonators can be used to remove tones from the exhaust spectrum. There are two major industrial facility applications that fall outside these categories, and are best silenced with specific combination reactive-absorptive mufflers. These sources are high-speed rotary positive blowers and high-pressure vents.

Both sources have substantial high and low frequency noise content, and can tolerate moderate pressure drop. As a general rule, reciprocating or positive displacement machines should be attenuated with reactive silencers, and centrifugal equipment should use absorptive silencers. For all remaining major noise sources, combined reactive-absorptive silencers are appropriate with many designs available to choose from.

A] WORKING OF MUFFLER:

Main function of muffler is to the sound reduction. But in the process of sound reduction by using resonance phenomenon the back pressure is created. This back pressure is created due to the exhaust gases which are flow through the chambers for creating resonance phenomenon for decrease the sound level of the exhaust gases. This back pressure creates the high pressure level in the exhaust pipe system. This back pressure is exerts pressure which are carried by exhaust line on the exhaust valve of the engine. Which results into delay in the opening of the exhaust valve and the power loss is takes place. Because of the back pressure the fuel consumption is also increased in the engine. In the designing of the semi active muffler silencer to decrease this back pressure is the main objective. In the new design of

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this muffler the butterfly valve is used between the chambers opening in the muffler. This is used for the bypass this system at a required specific situation and the back pressure which affects the engine power reduction this back pressure reduced because of the free flow of the system.

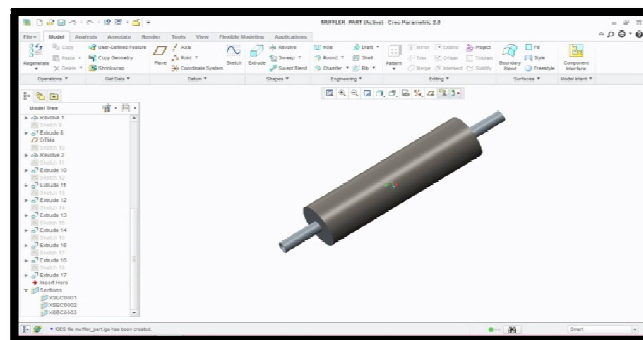


Fig.5 View of muffler using designing software.

Muffler contains the butterfly valve which is used for the bypass this system. This butterfly valve is used in the two conditions first in the closed condition where the muffler acts in the normal condition and the resonance phenomenon is used for the decrease the sound level of the exhaust gases. This is the normal working of the muffler which used in the automobile sector.

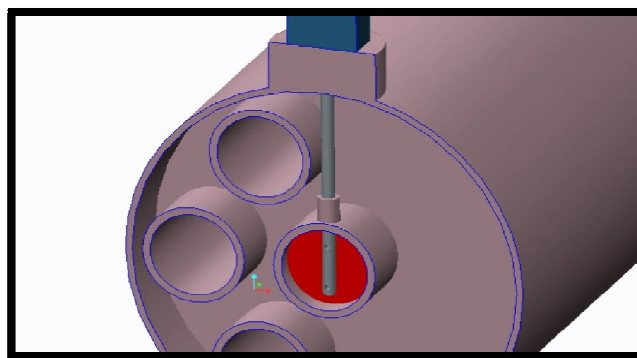


Fig.6 Butterfly valve in closed condition

When the high power required to the vehicle in the state of inclined road of the increase the speed the back pressure should be reduced which helps to decrease the power losses created due to back pressure. In the open condition of this butterfly valve the exhaust gases are suddenly throw out of the system and the phenomenon of the back pressure is decreases. This butterfly valve is located between the first and second chamber for the better performance. This valve also takes the help of the first chamber for decrease the sound level by using the resonance phenomenon.

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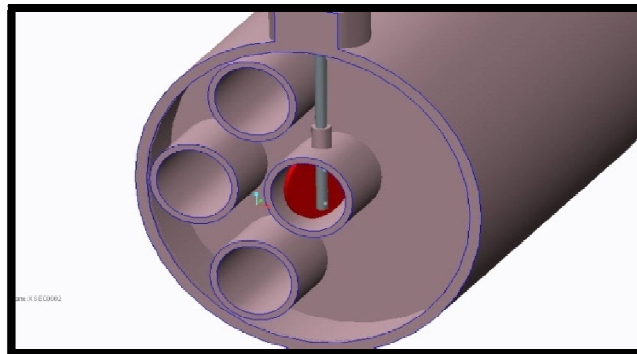


Fig.7 Butterfly valve in open condition.

By using this type of arrangement the back pressure is reduced for the better performance of the engine and the efficiency also increased due to decrease in the fuel consumption. This type of muffler is compatible with the situation of the working of the vehicle according to the requirement the working of the muffler can be modified for better performance. Internal combustion engine is a major source of noise pollution. These engines are used for various purposes such as, in power plants, automobiles, locomotives, and in various manufacturing machineries. Noise pollution created by engines becomes a vital concern when used in residential areas or areas where noise creates hazard.

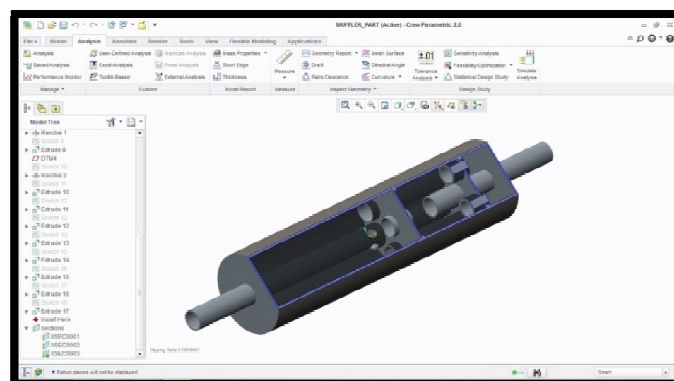


Fig.8 Muffler chambers iso-metric section view.

This is the arrangement of the chambers in the muffler system the fig 8 shows the section view of the muffler chambers used in the automobile industry in now a day. This system is used for the decrease the sound level.

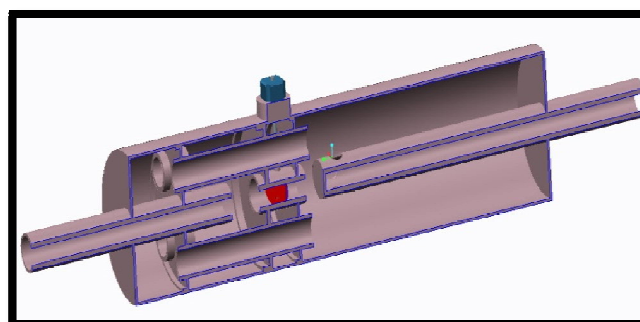


Fig.9 Muffler section view with butterfly valve in isometric view.

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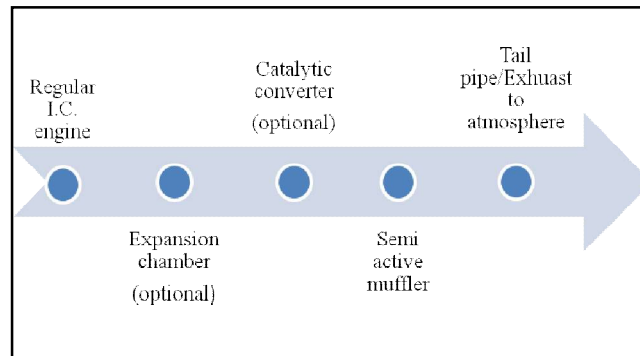


Fig.10. Working flow of the semi active muffler exhaust system.

ADVANTAGES:

Advantages of semi active muffler exhaust system:-

1. Sound attenuation in normal driving.
2. Reduce in back pressure to optimize air outflow when throttle starts to wide open.
3. Maximum utilization of the power generated by engine.
4. Fuel consumption is decreased due to decrease in the losses caused by back pressure.

The only effect is observed due to this system is the noise level is increased at the time of working of semi active muffler exhaust system. The decrease in the resonance phenomenon results in the increased sound level. This increased sound at a bypass situation between the chambers is disadvantage of this system. As in this state also the use of the first chamber in the decrease sound level is important utilization but the results are above the required specific conditions. Optimization of this system is according to the decrease the sound level after using this system.

VI. SCOPE AND OBJECTIVE

Study the result of performance and analysis of working of exhaust system using semi active muffler silencer. Comparing the performance and working efficiency of muffler using exhaust system and semi active muffler using exhaust system and analysis of the results and uses.

After studying the working of semi active muffler exhaust system developing the co-relations for working and optimization use of this system in commercial automobile industry.

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