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Semi Active Muffler

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ABSTRACT

An inherent drawback of IC engines is that it is a major source of noise pollution. That is why the reduction of exhaust noise from engines is, now days, an important issue. Attaching a muffler in the exhaust pipe is the most effective means of 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 RPMs , and converts in free flow when engine at higher revs.A semi active muffler basically operates in two operating conditions:1) Normal mode (High noise attenuation) and 2) Free Flow Mode (minimum back pressure). In normal operating the major objective is to attenuation of sound well below legal limits of sound pressure level. This muffler acts as a normal muffler giving typical performance of stock muffler made by vehicle manufacturers. The exhaust gases are forced to pass through various restrictions, baffles and sudden change in directions as a factory muffler is. In the free flow mode, the exhaust gases in the muffler are almost bypassed but not totally, by using only one expansion chamber for sound reduction instead of all three chambers. In this mode the exhaust gases enters the first chamber and then are exhausted to the atmosphere.

Keywords: Muffler, Engine, Catalytic

I. INTRODUCTION

Pass-by the noise for snowmobiles as well as other vehicles is an increasing concern. Although not the only source, a good portion of the noise emitted by snowmobiles originates from the exhaust system. Space and weight restrictions on a snowmobile can make it difficult to attenuate exhaust noise to a desirable level only using passive mufflers. The use of a semi-active exhaust system, stand either alone or in conjunction with a traditional passive muffler, offers the opportunity to achieve good exhaust noise attenuation while keeping size and weight to a minimum. The semi-active muffler approach achieves this by making the muffler element more efficient. This is accomplished by actively changing the physical parameters of the muffler. This changes its attenuation characteristics to be most beneficial for attenuating the exhaust noise at any engine speed or operating condition. Knowledge of the engine exhaust noise characteristics along with measurements of engine rpm and other parameters will allow this to be done in real time. In this dissertation, a thorough review of muffler acoustics is presented. The 4-pole parameter representation of mufflers is reviewed. Methods are employed for determining the 4-pole parameters of mufflers using experimental and boundary element modelling techniques. Muffler performance is quantified by Transmission Loss (TL) or Insertion Loss (IL) defined in terms of the 4-pole parameters. TL results determined by models and experiments are corroborated. A semi-active muffler design is introduced, developed, and analysed including refinement of the design after initial engine testing. The semi-active muffler is tested for functionality in the laboratory as well on a snowmobile engine. It is shown to function as designed, demonstrating the feasibility of the semi-active muffler concept. However, the added complexities of a semi-active muffler evidenced by this study suggest that only substantial size and weight savings coupled with improved attenuation performance would make the use of a semi-active muffler worthwhile. The findings tend to indicate that this may be very difficult to achieve. Nonetheless, the information provided in this dissertation will prove useful to future design of mufflers both passive and semi-active alike

II. METHODS AND MATERIAL

A. Literature Review

Er.Jinsiang Shaw (2012) et. Al has presented Design and Control of Active Muffler In Engine Exhaust Systems says, Active noise control (ANC) is often applied in various situations for suppressing wanted noise. Noise in a duct, engine exhaust systems, noise in a cabin are some examples in which ANC is widely applied. Compared to conventional passive noise control, ANC can provide advantages such as improved low-frequency performance, wideband noise suppression, reduction in size and weight in the structure, and adaptability. As is well known, on-acoustic signal related to the primary noise as a signal for synthesizing the reference input, e.g. signals from an accelerometer, a tachometer, or engine ignition signals. On the other side, broadband feed forward ANC measures directly the primary noise near the sound source as the reference signal. One drawback associated with the broadband feed forward ANC is the so-called acoustic feedback which originates from the control speaker and can cause undesirable effects. These two popular feed forward ANC structures have been extensively investigated induct noise applications. Instead of using two sensors in the feed forward ANC structures (one sensor for the reference signal, the other sensor for the residue sound level for tuning controller feedback.[5]

Er.Potente Daniel et. al (2005) has explained General Design Principles for an Automotive Muffler, says, the sole purpose of an automotive muffler is to reduce engine noise emission. If you have ever heard a car running without a muffler you will have an appreciation for the significant difference in noise level a muffler can make. If vehicles did not have a muffler, there would be an unbearable amount of engine exhaust noise in our environment. Noise is defined as unwanted sound. Sound is a pressure wave formed from pulses of alternating high and low pressure air. In an automotive engine, pressure waves are generated when the exhaust valve repeatedly opens and lets high-pressure gas into the exhaust system. These pressure pulses are the sound we hear. As the engine rpm increases so do the pressure fluctuations and therefore the sound emitted is of a higher frequency. All noise emitted by an automobile does not come from the exhaust system. Other contributors to vehicle noise emission include intake noise, mechanical noise and vibration induced noise from the engine body and transmission.[6]

Er.Peter Svanberg et.al (2011) has presented Analysis and design of a semi-active muffler, says, in flow duct applications, such as e.g. IC-engine exhaust systems on cars and trucks, high sound pressure levels area common problem. The sound is usually attenuated with a muffler in which two different types of silencing elements is used, reflective and resistive. Resistive elements are elements where the acoustic energy is dissipated as heat; such material is e.g. mineral wool and perforated plates. Reflective elements attenuate the sound by destructive interference between sound waves travelling in different directions. Some examples of these are area discontinuities and resonators like the quarter wave resonator and the Helmholtz resonator. Depending of the geometry, the reflective elements will have one or more regain frequencies with maximum attenuation. In this work, a reflective type of muffler, the flow reversal resonator, has been studied and modified to act as a semi-active muffler. The Flow reversal resonator. It is shown in that a flow reversal chamber may be modified with a short-circuit duct, connection the inlet and outlet, thus creating a resonator. The regain frequency of this resonator will change depending of the ratio between area and length of the short circuit duct, L/S, if the rest of the system is left unchanged.[1]

Er.Puneetha CG, Manjunath H, Shashidhar et.al (2015) has presented Backpressure Study In Exhaust Muffler Of Single Cylinder Diesel Engine Using CFD Analysis says, Using diesel engines mostly as main power element has increased the importance of the technical specification of the diesel engine itself and its other during-and-after design belongings. The muffler is defined as a device for reducing the amount of noise emitted by an Engine. The muffler is engineered as an acoustic soundproofing device designed to reduce the loudness of the sound pressure created by the engine by way of Acoustic quieting. Due to increased environmental concerns requiring less noise emissions combined with reduced emission of harmful gases, it is becoming very crucial to carefully design the exhaust system mufflers for road transport applications. Exhaust gas emitted from vehicles contains many components that contribute to air pollution, namely carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NOx).[3]

Er.JacekDybaa et. al (2012) with paper 'Thermal Analyses Of Exhaust System On Combustion Engine', says, Demand for energy continues to grow in our civilization while the non-renewable natural sources of energy are inevitably vanishing. Oil mining is becoming increasingly difficult and expensive. Also other sources of energy are used, e.g. natural gas, shale gas, solar energy, wind energy, however there is increasing talk about efficient use of energy and recovery of energy. Automotive industry develops new systems and methods of re-use of the energy lost in the process of its generation, including also re-use of thermal energy. As we know from the heat balance of a combustion engine, there is no possibility of transforming the entire thermal energy obtained in the process of burning the air-fuel mixture in to mechanical energy. Only 25-40% of the heat supplied to the engine is transformed into mechanical energy. Part of this energy is used for powering the systems located inside the engine, such as e.g. the timing gear system or the cooling system pump. The remaining part of the energy, some 60-75%, is emitted together with the exhaust fumes or is absorbed by the cooling agent. It is expected that recovery of 6% of the energy lost in the process could reduce fuel consumption by 10%.In order to employ thermal energy recovery systems, which are based on thermoelectric generators; a relevant operating environment should be designed in which the cells will not be damaged. According to Indian scientists, TEG cells can resist temperature of up to 220 degrees.[2]

Er.Lian-yun LIU, Zhi-yong HAO, Chi LIU et.al (2004) has presented Analysis Of A Transfer Matrix Of Exhaust Muffler With A Mean Flow And Prediction Of Exhaust Noise', says, Mufflers are widely used in intake and exhaust systems of internal combustion engines. The exhaust muffler comprising perforated pipes and porous media is employed to reduce the exhaust noise level, in both reactive and dissipative ways. Much work has been done in two fields: acoustic performance analysis of mufflers and exhaust noise prediction. The acoustic performance of the exhaust muffler has been widely investigated in terms of the noise reduction, transmission loss, and insertion loss. Since the exhaust muffler is increasingly complex inside, the plane wave theory (Prasad and Crocker, 1984;Munjal and Prasad, 1986; Munjal, 1987) is not adequate for analysing its acoustic performance. Numerical methods have been developed to meet there requirement of a higher accuracy. Yasuda *et al*. (2010)modelled a complex exhaust muffler by a 1D computational fluid dynamics (CFD) approach and predicted the tail pipe noise of an automotive muffler. The predicted noise showed a close agreement with the measured value at the 2nd order of the engine rotational frequency, while deviation existed at higher frequency, which is common for the 1D CFD approach.3D approaches based on frequency domain, such as boundary element method (BEM) (Cheng *etal*., 1991; Ji and Selamet, 2000; Hao *et al*., 2005) and finite element method (FEM), have often been employed to investigate the acoustic characteristics of mufflers.[4]

B. Effect 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 leads 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 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 resulting 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.

C. 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 atmospheres in amplitude as well as having pulse duration between 2 and 5 milliseconds. The frequency spectrum is related 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.

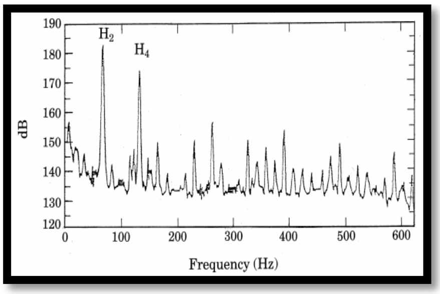

Fig.1 Engine Noise

A deep rapping noise from the engine is usually "rod knocks," a condition brought on by extreme bearing wear or damage. If the rod bearings are worn or loose enough to make a dull, hammering noise, you are driving on borrowed time. Sooner or later one of the bearings will fail, and when it does one of two things will happen: the bearing will seize and lock up the engine, or it will attempt to seize and break a rod. Either way your engine will suffer major damage and have to be rebuilt or replaced.

Bearing noise is not unusual in high mileage engines as well as those that have been neglected and have not had the oil and filter changed regularly. It can also be caused by low oil pressure, using too light a viscosity oil, oil breakdown, dirty oil or dirt in the crankcase, excessive blow by from worn rings and/or cylinders (gasoline dilutes and thins the oil), incorrect engine assembly (bearings too loose), loose or broken connecting rod bolts, or abusive driving.

Bearing wear can be checked by dropping the oil pan and inspecting the rod and main bearings. If the bearings are badly worn, damaged or loose, replacing the bearings may buy you some time. But if the bearings are badly worn or damaged, the crankshaft will probably have to be resurfaced -- which means a complete engine overhaul or replacing the engine is the vehicle is worth the expense.

D. Main Components Of Exhaust System

a. Exhaust Manifolds

An exhaust system is usually piping used to guide reaction exhaust gases away from a controlled combustion inside an engine or stove. The entire system conveys burnt gases from the engine and includes one or more exhaust pipes. Depending on the overall system design, the exhaust gas may flow through one or more of:

Fig.2. Exhaust Manifolds

b. Catalytic Converter

I am sure you must have heard about Catalytic Converters but what actually are they and how do they work. The article is an attempt to make you understand the functioning and utility. Our concern about the Global warming and increasing atmospheric pollution due to automobiles expelling pollutants as toxic gases from their

Exhaust towards the Catalytic converter is a set of steel box fitted generally in between the exhaust bend and the expansion chamber. One can spot a catalytic converter in a modern motorcycle or a scooter as a rectangular box or cylindrical attachment/protrusion in the exhaust pipe. Inside the catalytic converter there is honeycomb, shaped structure made by ceramic and are coated by "Catalysts" like Platinum or metal like Palladium or Rhodium. These metals are called "Catalysts" as due to their presence the molecules of toxic gasses like Carbon-mono-oxide and Nitrogen Oxide splits into inert and non-hazardous gas particles like Nitrogen, Carbon Dioxide and Water. The character of a Catalyst is, that it never reacts with the reagent and nor it changes its own form. Virtually a catalyst is something that boosts the reaction without directly undergoing into the process but its sheer presence speeds up the whole process. Therefore, at the Catalytic converter, the catalyst like Platinum speeds up the process of converting the toxic molecules into harmless atoms, which generally never get a chance to split into simpler form and expelled out as it is from the exhaust in the absence of Catalytic converter.

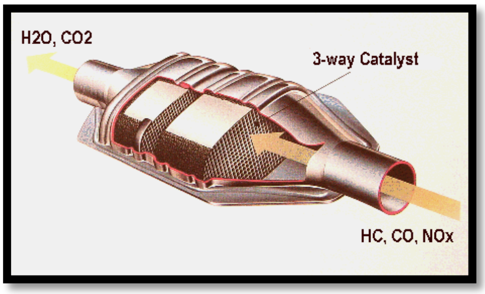

Fig.3.Catalystic Convertor

b. Muffler

A muffler (silencer in many non-US English speaking countries) is a device for decreasing the amount of noise emitted by the exhaust of an internal combustion engine.

Fig.4. Muffler

c. Tail Pipe

An exhaust system is usually piping used to guide reaction exhaust gases away from a controlled combustion inside an engine or stove. The entire system conveys burnt gases from the engine and includes one or more exhaust pipes. Depending on the overall system design, the exhaust gas may flow through one or more of, with trucks, sometimes the silencer is crossways under the front of the cab and its tailpipe blows sideways to the offside (right side if driving on the left, left side if driving on the right). The side of a passenger car on which the exhaust exits beneath the rear bumper usually indicates the market for which the vehicle was designed, i.e. Japanese (and some older British) vehicles have exhausts on the right so they are furthest from the curb in countries which drive on the left, while European vehicles have exhausts on the left. The end of the final length of exhaust pipe where it vents to open air, generally the only visible part of the exhaust system part on a vehicle, often ends with just a straight or angled cut, but may include a fancy tip. The tip is sometimes chromed. It is often of larger pipe than the rest of the exhaust system. This produces a final reduction in pressure, and sometimes used to enhance the appearance of the car. In the late 1950s in the United States, manufacturers had a fashion in car styling to form the rear bumper with a hole at each end through which the exhaust would pass. Two outlets symbolized V-8 power, and only the most expensive cars (Cadillac, Lincoln, Imperial, Packard) were fitted with this design. One justification for this was that luxury cars in those days had such a long rear overhang that the exhaust pipe scraped the ground when the car traversed ramps. The fashion disappeared after customers noted that the rear end of the car, being a low-pressure area, collected soot from the exhaust and its acidic content ate into the chrome-plated rear bumper

III.RESULT AND DISCUSSION

A. 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.

B. Typical Muffler Designs:

Two typical reactive muffler designs. The first design is frequently chosen because of its low cost and because it causes a lower back pressure. The second design 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 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. 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. The maximum back pressure allowed for a Continental O-150 or a Lycoming 540 engine is 1 psi. Typical mufflers of the type generate minimal back pressure, while those of the type were measured during this study as having 1.4±0.2 psi of back pressure.

C. 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 usually 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. Two major industrial facility applications 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.

D. Working Of Muffler:

Main function of muffler is to the sound reduction. However, 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 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 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. 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. 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 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 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 areas where noise creates hazard.

IV. 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.
5. 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.

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