Design, Development and Analysis of Aqua Silencer with Ammonia Pulsator for IC Engine

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Abstract

Internal Combustion engines exhaust noise pollutes harmful in environment. That is the reason of reduction of exhaust noise & emission from the engines is a critical issue, now-a-days. Any type of engine exhaust noise is controlled by utilizing the silencers/mufflers. Attaching a muffler in the exhaust pipe is the most efficient method for reducing the noise. However, muffler requires particular design and development by considering different noise parameters produced by the engine. Here we are taking different design parameters with ammonia pulsator to improve the efficiency & emission control of the absorptive muffler. Aim of this work is to design, develop and analysis of mathematical modeling and derivation of dimensional parameters of absorptive muffler with ammonia pulsator using Solidworks and ANSYS workbench. The formulated muffler traditional design problem will be solved by new design and optimization.

Index Terms - *Absorptive Muffler, Engine Exhaust Noise and Emission Reduction, IC Engine*

I. INTRODUCTION

An IC engine is a major source of noise pollution. These engines are utilized for different purposes, for example, in automobiles, in power plants and in different manufacturing machineries. Noise pollution made by engines turns into a crucial concern when used in residential areas or areas where noise creates hazard. For the most part, noise level of more than 80 dB is harmful for human being. The main sources of noise in an engine are the exhaust noise and the noise produced because of erosion of different parts of the engine. The exhaust noise is the most prevailing. To reduce this noise, different kinds of mufflers are generally used. The level of exhaust noise reduction relies on the construction and the working strategy of mufflers.

The exhaust is passed through a progression of chambers in reactive mufflers or straight through a perforated pipe wrapped with sound deadening material in an absorptive muffler. Both types have their strengths and weaknesses. The reactive muffler is generally restrictive & prevents even the good engine sounds from coming through, but does good job of reducing noise. On the other hand, most absorptive mufflers are less restrictive, but allow too much engine noise to come through. Despite of the packing material, absorptive mufflers tend to get noisier with an age.

Absorptive mufflers use sound absorbing materials to attenuate sound waves. It is widely used in HVAC duct systems. Typical absorptive mufflers are configured in a parallel baffle arrangement. The motivation behind why we go for absorptive muffler is; in daily life the air pollution causes physical sick impacts to the individuals furthermore the earth. The main contribution of the air pollution is automobiles discharging the gases like CO_2, unburned hydrocarbons and so forth, in order to avoid such gases by introducing this absorptive muffler. It is fitted to the exhaust pipe of the engine; Sound delivered submerged is less hearable than it produced in atmosphere.

The objective of this work is to obtain a muffler with optimal acoustic performance in relation to its size or volume, as well as a reduction in the counter pressure to the flow of gases, i.e. while at the same time reducing the noise, it also minimizes the power it takes away from the engine of the vehicle. By Mathematical modeling we will be calculate dimensions of the muffler; modeling will be done in Unigraphics or CatiaV5 software, stress analysis is to be done using Finite Element Analysis (FEA using ANSYS workbench 14.5 for structural analysis, ANSYS ICEM for mesh and ANSYS FLUENT for CFD analysis).

A. Typical Muffler Designs

There are two typical muffler designs are shown in Fig.1. And Fig.2. The first design, shown in Fig.1, is frequently chosen because of its low cost and because it causes a lower back pressure. The second design as shown in Fig. 2 which gives more attenuation and is typical of the design recommended by muffler manufacturers. However there is no direct connection between the inlet and the outlet so back pressure is generated that can impact engine performance. This is in some cases referred to as a baffled muffler design.

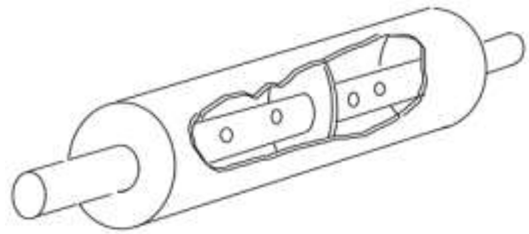

Fig.1. Sketch of typical muffler with two cavities and no flow restriction

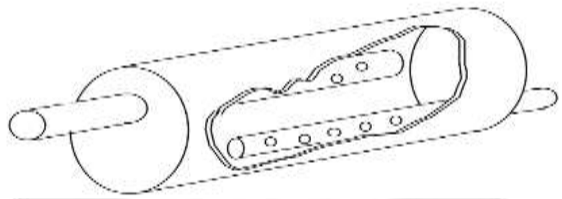

Fig.2. Sketch of typical muffler in which there is no direct passage between the inlet and exit

II. LITERATURE REVIEW

The literature review focuses on the literature study done on the review of related journal papers, articles which available for an open literature.

Vijay M Mundhe which describes, muffler is an essential part of an engine system used in exhaust system to decrease exhaust gas noise level. The literature survey reveals that the exhaust gas noise level relies on different factors. Muffler geometry, extension in inlet and outlet valves, number of whole perforations and its diameter are the factors which influences noise from engines. The objective of this study is to decrease exhaust gas noise level [1].

Jigar H. Chaudhari speaks on the various types of mufflers and design of exhaust system belonging engine has been studied. The object of this study is choosing muffler design which one reduces a large amount of noise level and back pressure of engine. In designing, there are various parameters which has to take in to the consideration. These parameters affect the muffler efficiency. Absorptive muffler design uses only absorption of the sound wave to reduce the noise level without disturbing the exhaust gas pressure [2].

Rahul D. Nazirkar explains an automotive exhaust system the noise level, transmission loss & back pressure are the most important parameters for the driver & engine performance. In order to enhance the design efficiency of muffler, resonating of the exhaust muffler should be avoided by its natural frequency. The design of muffler becomes more and more important for noise reduction. The solid modeling of exhaust muffler is created by CATIA-V5 and modal analysis is carried out by ANSYS to study the vibration and natural frequency of muffler, so as to differentiate between working frequencies from natural frequency and avoid resonating [3].

M. Rahman describes the absorptive muffler is the classic dissipative design, deriving its noise control properties from the basic fact that noise energy is effectively “absorbed” by different types of fibrous packing materials. That is, as the sound waves go through the spaces between the tightly packed, small diameter fibers of the absorptive material, the resulting viscous friction dissipates the sound energy as small amounts of heat [6].

III. MUFFLER SELECTION

In order to choose a suitable muffler type, some basic information are necessary with respect to how industrial mufflers work. Mufflers attenuate noise by two methods such as reactive attenuation and absorptive attenuation. The first method, reflects sound energy back towards the noise source and second method, absorbs sound by converting sound energy into the small amounts of heat.

There are three types of industrial mufflers that use these methods to attenuate facility noise – reactive muffler, absorptive muffler and anyone or both of them combined with resonator. The proper selection of a muffler is done by matching the attenuation characteristics of muffler to the noise characteristics of the source, while still achieving the allowable muffler power consumption caused by muffler pressure drop.

Industrial noise sources are divided two categories with specific characteristics. Category I cover sources that produce mainly low frequency noise and can tolerate relatively high pressure drops. Engines, rotary screw compressors, rotary positive blowers and reciprocating compressors are types of these sources. The nature of these machines is to generate low frequency noise and have pressure volume relationships that are quite tolerant of system pressure drop; such machines are perfectly suited for reactive mufflers. Category II covers sources that produce mainly high frequency noise and have performance is very sensitive for system pressure losses. These sources are always moving or compressing the fluid with spinning blades. For examples, includes turbines, centrifugal fans, etc. This kind of equipment is best treated with absorptive muffler for both low and high temperature applications.

IV. DESIGN OF ABSORPTIVE MUFFLER

A muffler have been designed by super critical grade type and it includes three attenuation principles i.e., reactive, followed by absorptive muffler, and a side branch resonator. The interesting events of the design are continuous volume reduction of chambers in the reactive part; the flow pipe cross-sectional area is maintained constant throughout, the placing of side branch resonator compactly, a layer of insulation outside the reactive part, option for tuning the resonator using a screw and cylinder.

A. Design Data

For our experiment, an existing petrol engine has been used. Calculations are done on the basis of data which collected from the engine; Specifications of the engine are available for the testing as follows:

TABLE I
SPECIFICATIONS OF ENGINE

Specification of the Engine	
Make: Crompton Greaves	Model: IK-35
Engine is two stroke spark ignition engine with the following specifications	
Bore diameter: 35 mm	Ignition: Flywheel magneto
Stroke: 35 mm	Way of rotation: Clockwise looking from the driving end
Capacity: 34 cc	Carburetor: ‘B’ type
Power output: 1.2 BHP at 5500 rpm	Cooling: Air Cooled engine
Torque: 1.76 N-m @ 5000 rpm	Lubrication: Mist –via petrol
Dry weigh: 4.3 kg	

However, some data are applicable to all types of engines. For designing, the following data are required.

1) *Sound characteristics (Without muffler)*
   Rpm of the engine = 5500
   Load Sound level
   Without any load 9.2 kg 104.5 dbA
   50% load 15 kg 106.5dbA
   100% load 24 kg 107dbA
2) *Sound analysis with the frequency analyzer (to obtain the dominating frequency):* Two dominating frequencies, the low level and high level have been obtained. These are Frequency Level (Hz): Low 270 and High 40000
3) *Diameter of the exhaust pipe of engine:* The Exhaust Pipe diameter: 1.0 inch (25.4 mm) - this is in accordance to the standard mounting flange on engine exhaust.
4) *The theoretical exhaust noise frequency range:* From the different experiments, it has been found that the theoretical exhaust noise frequency is 200-500Hz.

B. Muffler Part Design

S1 = Exhaust pipe diameter = 1.0 inch
The dimensions need to be determining that are the chamber length L and the body diameter S2.

1) *First method used to determine L:* Maximum attenuation occurs when

$$L = n\lambda/4 \qquad \ldots (1)\ [6]$$

Where, λ= wavelength of sound (m or ft), n = 1, 3, 5… (Odd numbers)
Since λ is related to frequency by the speed of sound, one can say that the peak attenuation occurs at the frequencies which correspond to a chamber length.

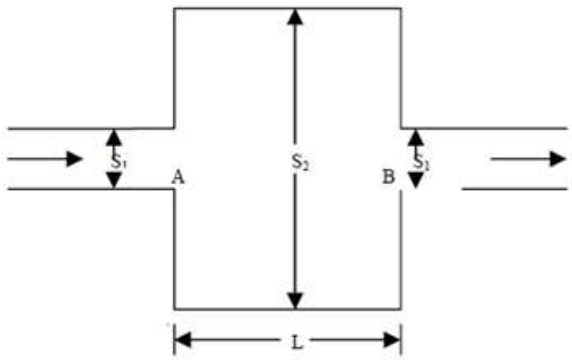

Fig.3. Schematic of muffler

TABLE II
CALCULATED WAVELENGTH FROM FREQUENCY

Frequency	λ = c/f (m)	λ (Inch)	N = odd integer	L = $n\lambda/4$ (inch)
N(Min)	0.5	19.6	1	4.9
200HZ	(Max)	(Max)	-	14.7
N(Max)	0.6	23.6	1	5.9
500	(Min)	(Min)	3	17.7

From the above Table II, we can find the length for the engine exhaust specifications is within the range of minimum 4.9 inches to maximum of 17.7 inches as most extreme conditions as never achieved because engine is always operated under load. Thus the length of the muffler smaller section is considered to be 5 inches & length of the overall section can be considered to be 17.7 inches or 450 mm.

2) *Range of the chamber length considering the temperature of exhaust gas:* Another factor which must be considered in expansion chamber design is the effect of high temperature of exhaust gases. This factor can easily be included in the design by using the following equation:

$$0.5(49.03\sqrt{°\mathrm{R}})/2\pi f \le \mathrm{L} \le 2.6(49.03\sqrt{°\mathrm{R}})/2\pi f \qquad \text{… (2)[6]}$$

Where, $\sqrt{°\mathrm{R}}$ = Absolute temperature of Exhaust Gas,
f = Frequency of Sound (Hz)

Let the temperature of exhaust is assumed to be 300º F / 759.7º R

Putting this value in equation (2),

$$0.5(49.03\sqrt{759.7})/2\pi 270 \le \mathrm{L} \le 2.6(49.03\sqrt{759.7})/2\pi 270$$

(Here, f = 270Hz for low frequency absorptive muffler)

$$0.4\,ft \le L \le 2.04\,ft$$

From the 1st method, L = 17.7 inch = 1.47 ft.
So the condition of $0.4\,ft \le 1.47 \le 2.04\,ft$ is satisfied.

C. Other parts of absorptive muffler design

It has always been considered that the flow path of diameter does not reduce at any point. Otherwise, there would be a possibility of back pressure. That is the reason; the following equation has been used to determine the diameter of smaller pipes, which are at the outlet of the first two chambers.

$$\pi S1^2/4 = \pi d1^2/4 + \pi d2^2/4 \qquad \text{… (3) [6]}$$

Where, d1 and d2 are smaller pipe diameters.

As both pipes are of the same diameter, one gets,

$$d1 = d2 = 1.06 \text{ inch}$$

Now, Total length L has been divided into three small chamber lengths L1, L2, and L3. As the pressure is dropping from the first chamber to next, we reduced the length slightly from the first to the third.

D.Tailpipe Design

According to the equation (1), resonance occurs when $L = n\lambda/2$. So, for an economical construction, value of n may be taken as 1. Then the tailpipe must be less than $\lambda/2$ i.e., 3"

E. Layout of Absorptive Muffler

An absorptive muffler consists of a perforated tube which is installed at the end of exhaust pipe. The perforated tube may have holes with different diameters and the purpose of providing the different diameters hole is to separate gas mass to form smaller gas bubbles. Generally four sets of holes are drilled on the perforated tube and at the other end of the perforated tube are closed by plug.

Around the circumference of perforated tube a layer of activated charcoal is given and further a metallic mesh covers it. The entire unit is then placed in a water container. A small opening is given at the Top of the container to remove the exhaust gases and a drain plug is given at the bottom of the container for periodically cleaning the container. Also a filler plug is attached at the top of the container. At the inlet of the exhaust pipe a non-return valve is provided which prevents the back flow of gases and water too.

1) *Description of Ammonia Pulsator:* The NOx in the exhaust gas cannot be removed easily by use of other devices like catalytic convertor, or carbon filter, hence a special device is required to remove this Nox from the exhaust gas. The pulsator is a device that sprays aqueous ammonia in the path of exhaust gases such that the NH3 combines with the oxygen in the exhaust gases and gets converted into HNO3 in mild form. Thus the exhaust gas is freed from the Nox gases.

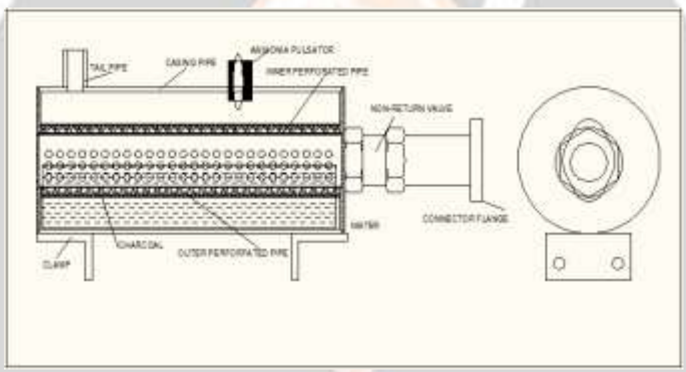

Fig.4. Absorptive Muffler with Ammonia Pulsator

F. Basic designs of absorptive muffler

1) Design of Casing Pipe:

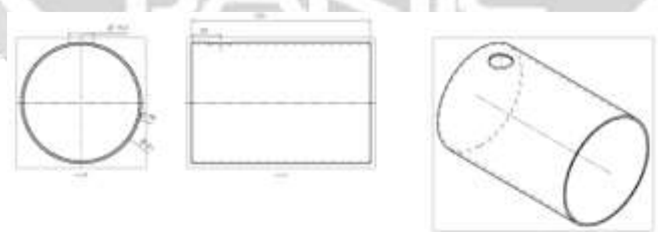

Fig.5. Geometry of Casing Pipe

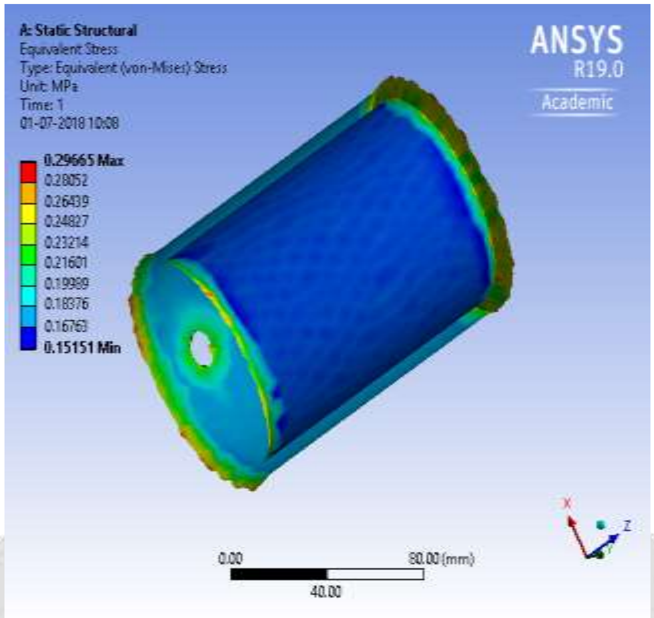

Fig.6. Structure with equivalent stress (von-mises) of Casing Pipe

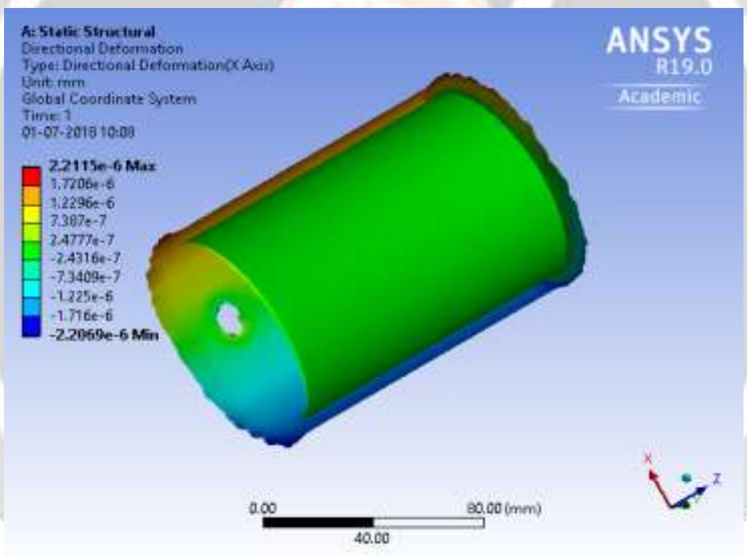

Fig.7. Structure with directional deformation of Casing Pipe

Hoope's stress due to exhaust gas pressure

Maximum pressure induced in system due to exhaust gases = 3 bar = 0.3 Mpa

$$fc_h = (p \times d)/2t$$

$$fc_{all} = (0.30 \times 81)/(2 \times 1.5)$$

$$fc_{all} = 0.81 N/mm^2$$

As $f_h < fc_{all}$; casing pipe is safe

Longitudinal stress due to exhaust gas pressure

Maximum pressure induced in system due to exhaust gases = 3 bar = 0.3 Mpa

$$fc_1 = (p \times d)/4t$$

$$fc_{all} = (0.30 \times 81)/(4 \times 1.5)$$

$$fc_{all} = 40.5 N/mm^2$$

As $f_1 < fc_{all}$; casing pipe is safe

2) Design of Charcoal Pipe – 1:

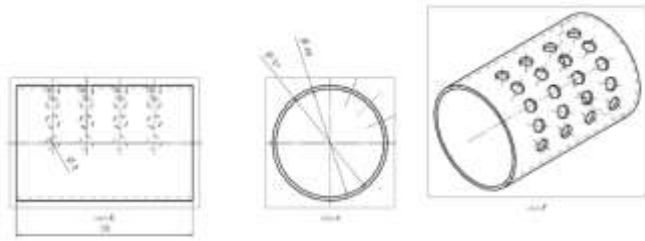

Fig.8. Geometry of Charcoal Pipe – 1

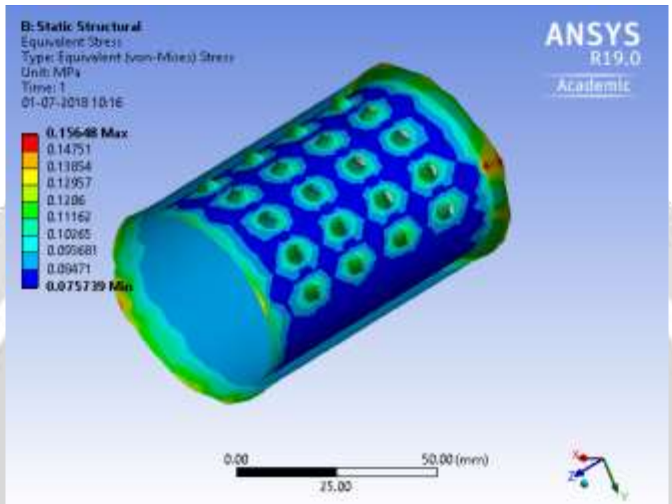

Fig.9. Structure with equivalent stress (von-mises) of Charcoal Pipe – 1

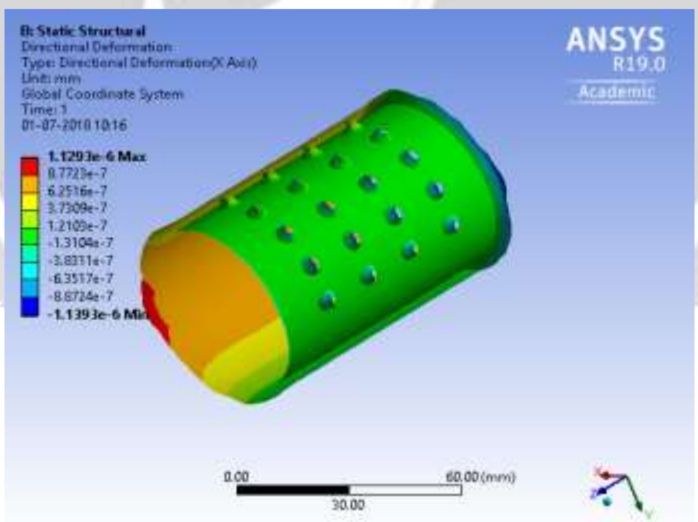

Fig.10. Structure with directional deformation of Charcoal Pipe – 1

Hoope's stress due to exhaust gas pressure

Maximum pressure induced in system due to exhaust gases=1.5 bar= 0.15 Mpa

Longitudinal stress due to exhaust gas pressure

Maximum pressure induced in system due to exhaust gases = 3 bar= 0.3 Mpa

3) Design of Charcoal Pipe – 2:

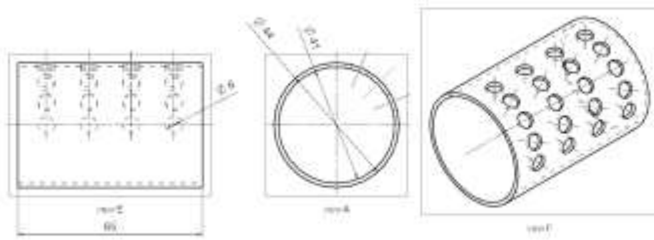

Fig.11. Meshing of Charcoal Pipe - 2

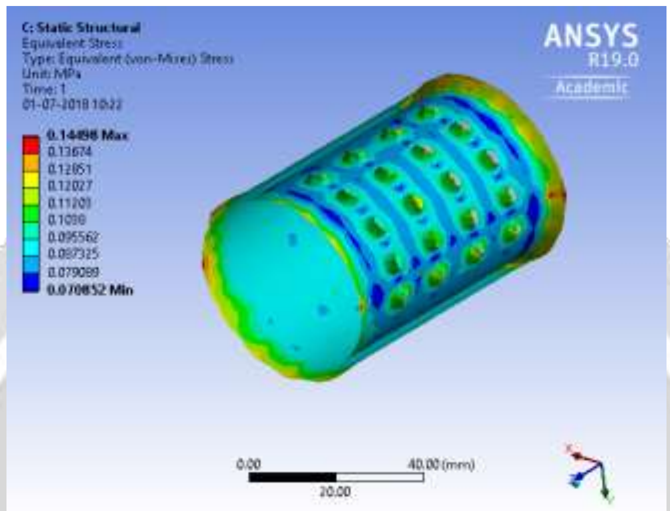

Fig.12. Structure with equivalent stress (von-mises) of Charcoal Pipe - 2

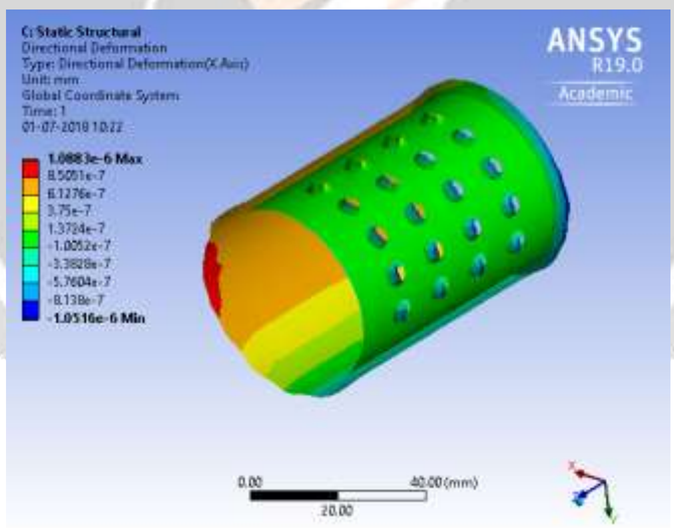

Fig.13. Structure with directional deformation of Charcoal Pipe – 2

Hoope's stress due to exhaust gas pressure
Maximum pressure induced in system due to exhaust gases=1.5 bar= 0.15 Mpa

Longitudinal stress due to exhaust gas pressure
Maximum pressure induced in system due to exhaust gases = 1.5 bar= 0.15 Mp a

V. RESULTS & DISCUSSION

The optimized design of muffler will be superior in terms of noise reduction capability and emission control than the existing one. The results from various tests are given below in the tabulated form.

A. Stress results of the casing pipe and charcoal pipes

In the comparison with von-mises stress, maximum stress by theoretical methods and von-mises are well below the allowable limits, it means that design of the casing pipe and charcoal pipes are the safe design.

TABLE III
STRESS RESULTS

Part Name	Maximum theoretical stress N/mm^2	Von-mises stress N/mm^2	Maximum deformation mm	Result
Casing Pipe	8.1	0.307	2.12E-6	Safe
Charcoal pipe-1	2.5	0.9	1.07E-7	Safe
Charcoal pipe-2	2.5	0.9	1.07E-7	Safe

B. Test and trail on engine without ammonia pulsator

CO (%) (Percentage of Carbon monoxide in unit volume of exhaust gas) - Reference value below 4.5 % for 2/4 stroke engines in 2 wheeler vehicles.
HC (n-Hexane equivalent ppm) - Reference value 9000 for 2/4 stroke engines in 2 wheeler vehicles.

TABLE IV
TESTING RESULTS

LOAD (KG)	SPEED (RPM)	NOISE (dBA)	C0 (%)	HC
0	4400	86	0.68	370
0.6	4240	88	0.91	399
1.2	3960	90	0.986	435
1.8	3720	93	1.18	459
2.4	3480	96	1.21	478
3	3360	98	1.27	522

VI. CONCLUSION

A comfortable environment free from undesirable noise and emission is always a dream of every human being. One of the sources of undesirable noises and emission is the IC engine exhaust. By using the different components to design the absorptive muffler with ammonia pulsator which will be reduce the unwanted noise and emission. In this project work, we performed the test on maximum theoretical stress of the pipes (casing pipe and charcoal pipes) used and test on engine without ammonia pulsator. The outcomes of the comparison with von-mises stress, maximum stress by theoretical methods and von-mises are well below the allowable limits, it means that design of the casing pipe and charcoal pipes are the safe design. The casing and charcoal pipe which demonstrates negligible deformation under the action of system of forces. The new optimized absorptive muffler with ammonia pulsator is designed for stationary engines and it can be utilized as a part in automotive exhaust with minor modifications.

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