Simulation of a New Design Muffler to Reduce Noise in Exhaust System of C-12 SI Engine

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Abstract- In this work, a finite element approach is presented for modeling and analysis of expansion type muffler are used often in the modern day's automotive exhaust system. The component is analyzed by using Pro-Mechanic a FEA tool, modal analysis is carried out on the expansion muffler to avoid resonance condition, natural frequency and mode shapes are presented. The design of silencer of SI engine is a key issue to attenuate or emphasize certain spectral components of tailpipe noise. The optimization of complex shape silencer system is generally a time-consuming operation, which must be carried out by means of concurrent experimental measurements and numerical simulations. This paper, aims to reduce exhaust noise produced from the exhaust system of C-12 portable 4-stroke SI engine. Exhaust gases from the engine is high pressure, these gases the noise would be tremendous for this reason, the exhaust gases are made to flow through a muffler, it consists of series of metal plates and tubes with required design aspects. Pressure of the gases is reduced when they pass through an expansion type muffler so that the gases out through tail pipe quietly.

Keywords: Muffler, Exhaust system and C-12 SI engine.

I. Introduction

The control of both the level and quality of internal combustion engine noise is a key aspect of the design process of a new automotive powertrain system, in order to satisfy the legislation limits and provide a pleasant interior and exterior sound [1]. Due to their broadband characteristics at mid to high frequencies, dissipative mufflers have been widely used in automotive exhaust systems [2]. Although a plane wave models are available for the prediction of the sound attenuation of mufflers at low frequencies [3]. Multidimensional analytical techniques are required for higher frequencies are to be considering the propagation of higher order modes [4]. While multidimensional analytical methods are desirable due to their low computational effort, they are not capable to model complex silencer geometries or non-homogeneous properties [6]. Young and Crocker applied the finite element method to reactive concentric expansion silencers to predict their transmission loss [7]. Finite element models for bulk reacting absorbent materials were presented by Kirby to consider perforated dissipative mufflers with homogeneous properties [8-9]. The absorbent materials considered were assumed to be homogeneous. However, in realistic cases of automotive silencers, this assumption is not always fulfilled and heterogeneous acoustic properties of the fibrous materials appear, the presence of these non-homogeneous properties may arise uneven filling processes in dissipative mufflers and degradation produced by the flow of soot particles within the absorbent material, these two phenomena can cause significant variation in the filling density of the fibrous material, which as a consequence leads to heterogeneity of its equivalent complex density and speed of sound, the muffler accomplishers this with a resonating chamber, which is specifically tuned to cause destructive interference, where opposite sound waves cancel each other out [5]. Expansion-box mufflers are the simplest, and they are rarely found, which has both the inlet and outlet pipes extended into the silencer chamber and perforations are made over both the pipes. The exhaust gas entering into the inlet pipe is allowed to expand through the perforated holes made over the inlet pipe, after expand the gases to strike over a baffle plate axially.

The gases are escapes from one side to the other through the inlet side of the silencer chamber. Finally the gases are out through the perforations made over the extension of the tail pipe. The gases emerge from the outlet are less energetic so that, it much quieter than the gas that enters the expansion box. In practice, a large expansion box is needed to give an appreciable reduction in noise so that, the expansion muffler are seldom used, unless it conjunction with another type, while designing a silencer [10]. Model analysis is carried out to find the natural frequency of the system to avoid resonance conditions in the operations. The expansion muffler concept has analyzed in Pro-Mechanica. The muffler absorbs sound waves and reduces the noise to socially and legally acceptable level. Redesigned muffler is attached with C-12 portable petrol engine as shown in Table 1.

Table I Engine Specifications Of C-12 Portable Petrol Engine

Engine Type	**C-12 Petrol Engine**
No. of cylinder	Single cylinder
Compression ratio	4.5 : 1
Bore (mm)	55
Stroke (mm)	50
Max power	1.2 kW, 2600 rpm
Load	1.1 – 1.2 kW
Max torque	3.3 Nm, 3600 rpm
Cooling system	Forced air cooling
Ignition timing	280 BTDC (fixed)

II. Existing and New Design Muffler

The parameters are changed with the existed and new design mufflers are below:

- Volume of the silencer should be greater than 6 times the volume of the cylinder of the engine.
- Diameter of the silencer should be greater than 2.5 times the diameter of inlet pipe.
- The diameter of tail pipe should not be more than half the diameter of the silencer chamber.
- The maximum length of silencer chamber can be up to 4 times the diameter of silencer chamber.
- A well designed silencer chamber should not reduce the power of the engine.
- The best efficiency of the silencer obtained with a loss of power 2 – 3%

A. Existing Mufflers

The parameters of an optimal design, which serves a compromise between the technical and economic factors:

Table II Specifications of existing muffler

Existing muffler	**C-12 Petrol Engine**
Diameter of inlet pipe	1.8 cm
Length of inlet pipe	11.5 cm
Volume of inlet pipe	29.25 cm^3
Volume of silencer chamber	235.3 cm^3
Total volume of silencer	264.55 cm^3

The design is not safe, because the amount if the total volume is very less comparing to required value that 720 cm^3 (six times the volume of the cylinder)

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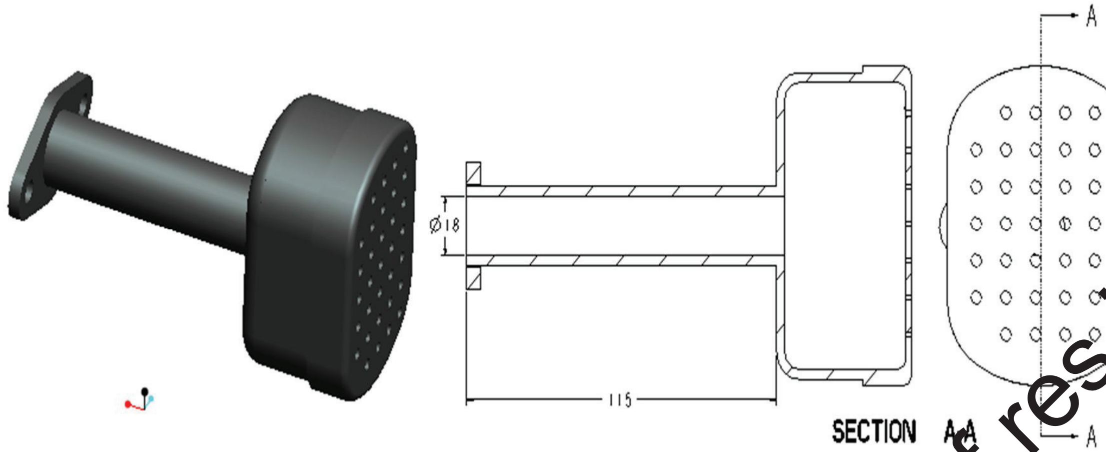


Figure 1 Existing muffler for C-12 Petrol engine

B. New Design Mufflers

The parameters of a new design expansion type muffler for exhaust system of portable single cylinder, 4-stroke spark ignition engine, as show in Table III.

Table III Specifications Of new design muffler

New design muffler	C-12 Petrol Engine
Diameter of the silencer	7.0 cm
Length of the silencer	19.0 cm
Diameter of inlet pipe & outlet pipe	2.2 cm
Volume of inlet pipe & outlet pipe	11.4 cm^3
Volume of silencer chamber	730.8 cm^3
Total volume of silencer	753.6 cm^3

The amount of total volume is greater than the required volume i.e. 720 cm3 so that, the design is safe, as shown in Figure. 2.

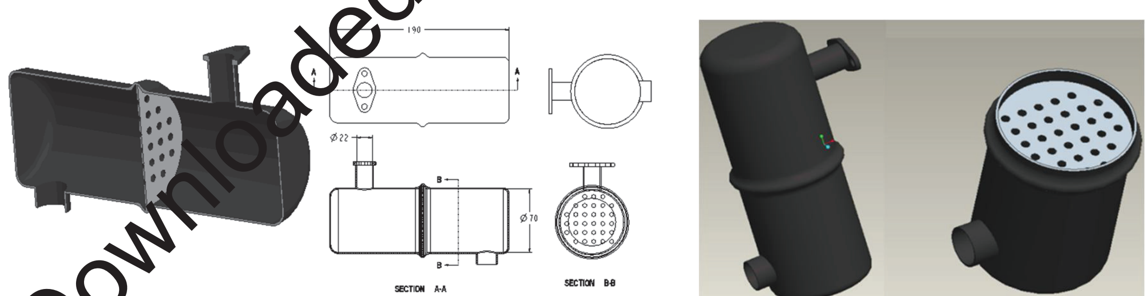


Figure 2 New design muffler

III. Experimental Setup

During testing the engine, the output is direct to the circuit, and the load varies with the help of regulator, because engine is coupled with the DC dynamometer; it converts the rotation (mechanical energy) into current (electric energy), as shown in Figure. 3

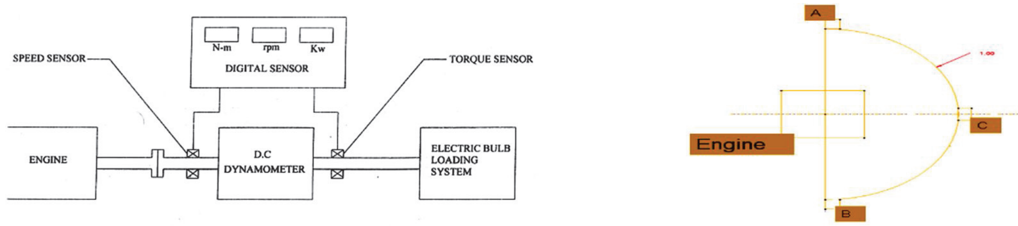


Figure 3 Digital lay out testing system

a. Testing of Silencer

The noise is measured from a fixed reference. A semicircle of 1 meter radius of the exhaust pipe outlet as the center point of the semicircle, 3 points are marked along the circumference of the circle and the points are marked as shown in Figure. 3, after testing the both existing and new designed muffler to obtain the average sound levels are shown in Table.4 and 5

TABLE IV
EXISTING MUFFLER WITH AVERAGE SOUND LEVEL 86.77

Position	Load (kW)	Speed (rpm)	Torque (Nm)	Sound Level-dB
A	-	3160	3.45	84
B	-	3160	3.34	83
C	-	3160	3.34	84
A	1.1	3100	1.27	85
B	1.1	3100	1.27	85
C	1.1	3100	1.27	85
A	1.2	3040	1.10	86
B	1.2	3040	1.10	87
C	1.2	3040	1.10	87

TABLE V
NEW DESIGN MUFFLER WITH AVERAGE SOUND LEVEL 74.44

Position	Load (kW)	Speed (rpm)	Torque (Nm)	Sound Level-dB
A	-	3160	3.34	84
B	-	3160	3.34	83
C	-	3160	3.34	84
A	1.1	3100	1.27	85
B	1.1	3100	1.27	85
C	1.1	3100	1.27	85
A	1.2	3040	1.10	86
B	1.2	3040	1.10	87
C	1.2	3040	1.10	87

The new designed silencer is tested with 3 load conditions: without load, with load and maximum load. The measurement of noise from the silencer outlet is measured using audiometer or sound level meter. The sound level meter is kept at a fixed reference from the silencer outlet, during testing the engine is made to run with the existing silencer. After 15 min first set of readings are noted at three points marked over the arc. The engine is allowed to run continuously for a prolonged period of time and it is seen whether any deceleration takes place, also the same methods are followed for other models.

b. Vibration, Resonance and Mode Shapes

A number of terms used to describe mode shape eigenvectors, normal modes, characteristic vectors or latent vectors. The five mode of vibration for an aerofoil are shown in Figure.4

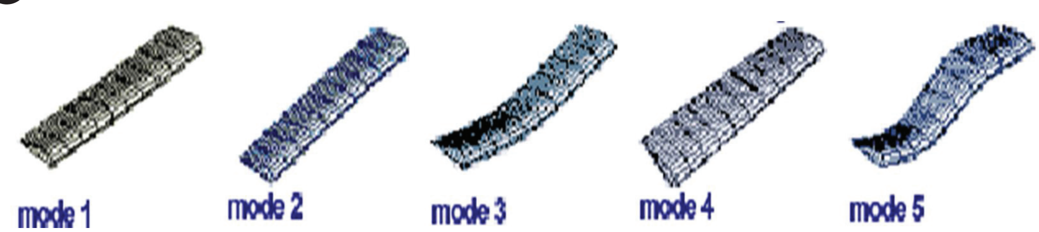


Figure. 4 Digital lay out testing system

c. Frequency Analysis

Modal analysis is used to determine natural frequencies within the range of operations. Alternatively, measured mode shapes and natural frequencies of a structure can be compared with those predicted by FEA in a condition monitoring program to verify structural integrity. The response of the structure to a particular forcing excitation is required, using a technique of modal superposition. The overall response is described in terms of a sum of modal responses, with the contribution of a particular mode given by the proximity of the forcing frequency to the natural frequency and the amount of damping present in the system. The response is dominated by modes near to the excitation frequency and therefore the modal series is often truncated to reduce computation. Frequency based analysis perform eigenvalue extraction to calculate the natural frequencies and corresponding mode shapes of a 'free system' (i.e. with no time dependent loads applied).

Modal-dynamic analysis is transient in nature. It gives the response for the model as a function of time where a cyclic (sinusoidal) load is applied to the structure. Modal-dynamic analysis is also referred to as forced harmonic response analysis. Complex displacements and phase angles are evaluated and deflection & stresses may be calculated at specific times, this analysis type is formulated on the principle of modal superposition, and so a natural frequency analysis must be carried out first. The modal amplitudes are integrated through time & the response is subsequently evaluated, this analysis solution must be linear in nature (in time domain), as superposition & Eigen value extraction techniques cannot be applied to non-linear time domain application.

Figure. 5 Meshing & Boundary condition of Muffler

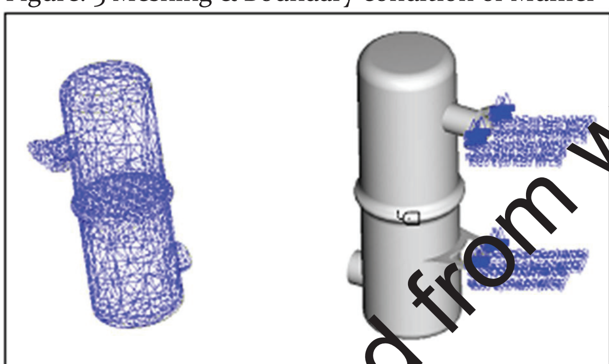


Figure. 6 Mode shape:1

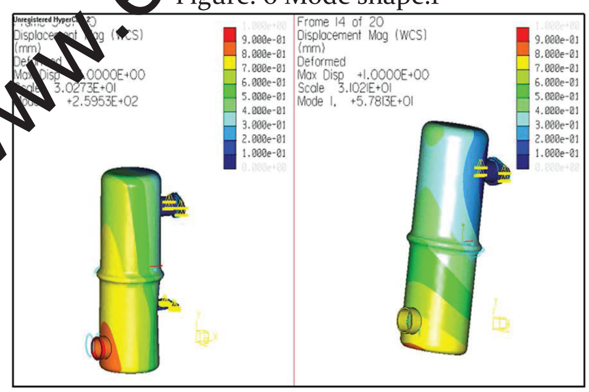
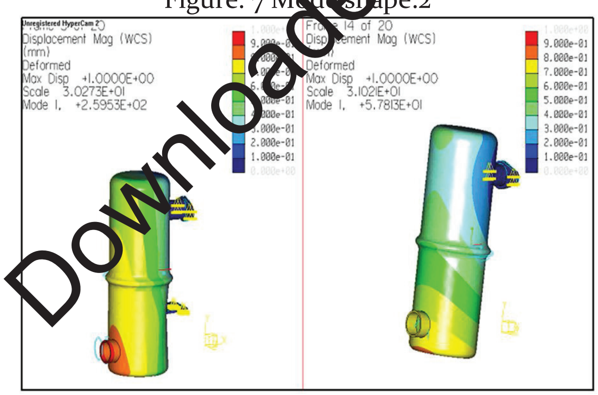


Figure. 7 Mode shape:2

Figure. 8 Mode Shape:3



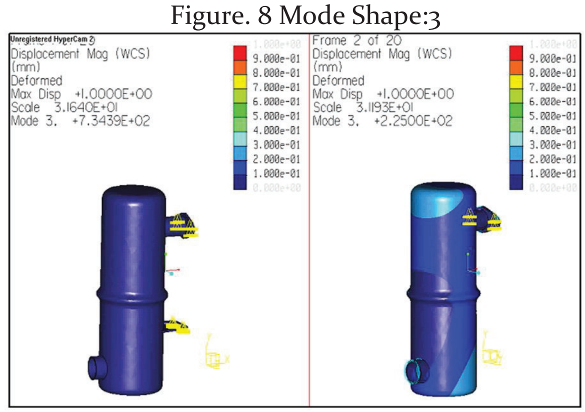
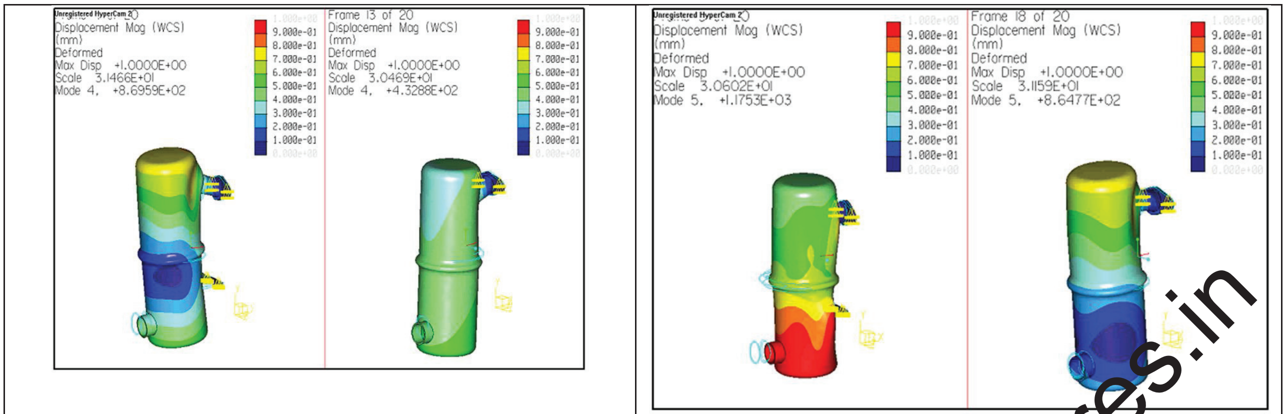


Figure. 9 Mode shape: 4

Figure. 10 Mode shape: 5



IV. Results and Discussions

A total of 30682 nodes and 30429 elements are used, all the degrees of freedom are arrested. For a large number of noise, vibration or durability related issues, modal analysis essential in discovering the root causes of the problem, stop acting on the symptoms only and gain a profound insight into the true nature of product weak spots as a first step in tackling those natural frequency of the system is above the maximum applied frequencies, so the system will work properly without any resonance nature as shown in Figure. 11. The design iterations are carried out for with bracket and results were compared with current design. Both the results are above maximum frequency level so the design is very safe in its structural behavior.

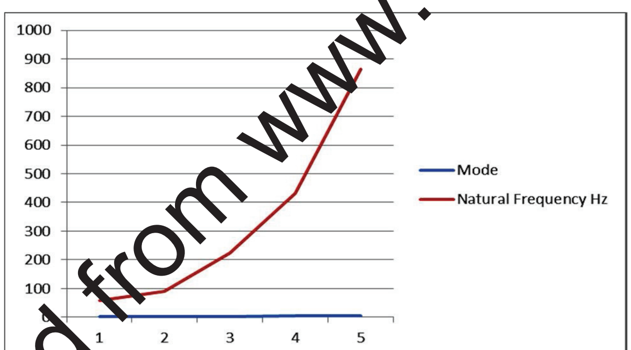


Figure. 11 Mode vs. Natural frequency of the system

V. Conclusion

1. It can be concluded from the experimental results that the sound level was reduced with the new design of muffler.
2. It is economical and in terms of reliability it has a longer life compared to the existing design
3. In this design, the baffles and reverse flow type model were eliminated for avoiding the back pressure in the exhaust.
4. The modal analysis frequency was tested with various modes-until the acceptable range, for eliminate the resonance in the chamber.
5. The various modes were tested, and it shows the natural frequency of the expansion type muffler was greater than the system frequency so that, the design is safe.

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