PARAMETRIC DESIGN OPTIMIZATION OF A REACTIVE MUFFLER
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ABSTRACT
The main objective of the project was to analyze the effect of the transmission loss of a muffler by varying the geometrical parameters such as the length, diameter of the single expansion chamber and the outlet of the muffler. Mufflers are mainly classified as dissipative and reflective type. The performance of a reactive muffler is given by the transmission loss (TL) of acoustic energy within the muffler. Plane wave theory is used to calculate the transmission loss of single expansion mufflers. Using this Generalized matrix method (GMM), the transmission loss can be found out by substituting the values of the geometrical parameters in the programs developed and then to run the program to find the transmission loss. Here the taguchi method is used for optimization.

INTRODUCTION
Exhaust noise of IC engine is one of the major concerns of pollution in the society. Mufflers are devices attached to the exhaust of IC engines to diminish the noise. Mufflers are mainly classified as dissipative and reflective type. In reflective type, the acoustic energy is reflected back by area discontinuities since it consists of number of tubular elements of different transverse dimensions joint together. Reflective mufflers are most effective in low frequency range and due to area discontinuities; it reflects a substantial amount of incident power back to the source due to the mismatch of characteristic impedances.

When the wavelength ‘λ’ of sound passing through a muffler is large compared to the transverse dimensions of the tube, the wave motion is nearly one dimensional, i.e. a plane wave. Therefore plane wave theory is commonly used for finding the attenuating effect of a muffler. The optimum parameter used to analyze the effect of a muffler is transmission loss. The performance of a reactive muffler is given by the transmission loss (TL) of acoustic energy within the muffler. The plane wave theory is used to calculate the transmission loss of single expansion mufflers. Plane wave theory is less complex as compared to other methods and also at low frequencies it gives satisfactory results, plane wave results shows a very close convergence with the results obtained from other methods such as FEA, BEM, WAVE, and TMM etc.

This analytical method or theoretical method is less flexible and become more complicated when complex geometries are analysed. But these limitations are nullified on generalized matrix method (GMM), upon which this study is based.

The GMM was used to analyse the acoustical behaviour of different geometries. The varying length of the chamber, length and diameter of the interconnecting tube were analysed. These variables were inserted into a software program to find the transmission loss and graphs were plotted.

Optimum muffler design for a particular IC engine for maximum sound attenuation is a major concern in automobile industry. The study pertains to a single expansion reactive muffler. Analyzed by varying its geometrical parameters and optimize the parameters for minimum transmission loss. Effect of interconnecting tube in a single expansion chamber is analyzed and optimized and
integrated it into the single expansion chamber for maximum Transmission loss.

**OBJECTIVE**
The main objective of the project is to
1. Study and analyze a single expansion chamber reactive muffler.
2. Analyze the effect of geometric parameters on transmission loss using plane wave theory.
3. Optimize the geometric parameters to get minimize transmission loss under the desired working condition.

**PARAMETRIC ANALYSIS OF THE EXISTING SINGLE EXPANSION CHAMBER REACTIVE MUFFLER**

The deals with attenuating effect of the muffler analyzed by varying the geometrical parameters. Attenuating effect is measured by using transmission loss. It is desired to analyze the effect of geometric parameter to increases the attenuating effect. The inlet diameter of the expansion chamber cannot be altered because of the back pressure effect and it demands the redesigning of the engine specifications. Here the geometric parameters such as length \((L_e=0.35\text{m})\), outlet diameter \((d_o=0.04\text{m})\) and diameter of the chamber \((d_c=0.16\text{m})\) can be varied and analyzed.

![Diagram of a single expansion chamber muffler](image)

**ANALYSIS BY VARYING THE LENGTH OF THE EXPANSION CHAMBER \((L_e)\)**

Out of the three parameters the inlet diameter, outlet diameter, diameter of the expansion chamber, Only the length of the expansion chamber is varied. Then the resulting transmission loss are obtained. The values of the length of the expansion chamber is taken as \(L_e=0.30, 0.32, 0.34, 0.35, 0.36\) and \(0.38\text{m}\).

The values are selected according to the manufacturing constraints and the length of chamber of the existing muffler is \(0.35\text{m}\).

While analyzing it is seen that as the length of the expansion chamber increases, the peak transmission loss doesn’t vary and length of loop is decreasing i.e. the loop frequency range decreases and there by number of loop in a particular range also increases linearly with the increasing length from the fig 5.2, the peak TL is 18 dB and this value remains constant. So it can be inferred that, as the length of the chamber increases, the TL curve gets compressed i.e. cut off frequency is reducing and sound can be attenuated more effectively.

<table>
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<th>Set No</th>
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**ANALYSIS BY VARYING THE DIAMETER OF THE EXPANSION CHAMBER**

The acoustical behavior of the single expansion chamber reactive muffler is analyzed by varying the diameter of the expansion chamber. Other geometrical parameters such as the length, inlet and outlet diameter is kept as a constant. Inlet pipe diameter of the single expansion chamber \(d_i=0.04\text{m}\), diameter of the outlet tube \(d_o=0.04\text{m}\), length of the expansion chamber \(L_e=0.35\text{m}\) and the diameter of the expansion chamber is taken as \(0.13, 0.14, 0.16, 0.17, 0.18\) and \(0.19\text{m}\) the expansion chamber diameter of the existing muffler is \(0.16\text{m}\).
Analyzing the diameter of the expansion chamber, it is seen that as the diameter of the expansion chamber increases the TL also increases and cut off frequency is decreasing i.e. sound can be attenuated more effectively. From fig 5.4 it is clear that peak transmission loss increases as the diameter increases. As there is limitations in increasing the diameter of the chamber for automobiles diameter is varied only up to 0.19m.

ANALYSIS BY VARYING THE OUTLET DIAMETER OF THE MUFLER

The acoustical behavior of the single expansion chamber reactive muffler is analyzed by varying the diameter of the tube. Other geometrical parameters such as the length, inlet and diameter of the chamber is kept as a constant.

Inlet pipe diameter of the single expansion chamber di=0.04m, diameter of the outlet tube dc =0.16m, length of the expansion chamber le=0.35m and the diameter of the outlet tube is taken as 0.01, 0.02, 0.04, 0.06 and 0.08m and the diameter of the existing muffler is 0.04m the values range is selected according to the manufacturing constraints.

On analyzing it is clear that as the outlet diameter of the muffler increases TL is increasing and when diameter decreases cut off frequency is moving negative region. and the sound can be attenuated more effectively.

From fig it is seen that maximum TL is at diameter of 0.08m, since there is a limitation I increasing the outlet diameter of the muffler variation is limited to 0.08m.

INTRODUCING AN INTER - CONNECTING TUBE TO THE EXISTING MUFLER

An interconnecting tube of diameter (dc) and length (lc) is introduced into the single expansion chamber muffler and its effect is to be analyzed. also the effect of its diameter and length should be investigated the geometrical details of the interconnecting tube in the single expansion chamber is given ; diameter of the interconnecting tube is 0.04m and the length of the interconnecting tube is 0.16m. The figure shows the single expansion chamber muffler with interconnecting tube.

The transmission loss obtained from the insertion of the interconnecting tubes is very much higher. The peak transmission loss obtained is 41dB. An interconnecting tube is added into the internal combustion engine 350cc and then they are analysed for the transmission loss. Here the single expansion chamber muffler geometrical parameters are kept as constant along with the diameter of the interconnecting tube. The only geometrical parameter varied is the length of the interconnecting tube. The values of the length of the interconnecting tubes is taken as 0.100, 0.140, 0.160, 0.175, 0.180 and 0.200m.
Fig - Single expansion chamber muffler with interconnecting tube

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Fig - Variation of transmission loss in varying the geometrical parameters of the interconnecting tube.

RESULTS AND DISCUSSIONS

The analysis is mainly done on the existing muffler by varying the geometric parameters such as length of the expansion chamber, diameter of the expansion chamber and also the outlet diameter of the muffler. Optimization is accomplished to the muffler design by varying the geometrical parameters.

COMPARISON OF TL OF OPTIMIZED DESIGN WITH THE EXISTING MUFFLER

Geometrical parameters of the existing muffler is considered and by varying these parameters through local optimization technique. This optimization technique gives the optimized geometrical parameters for higher transmission loss. The optimized geometrical parameters were: length of the chamber( Le) is 380mm, diameter of the chamber(Dc) is 190mm, inlet pipe diameter (Di) is 40mm and the outlet tube diameter (Do) is 80mm. A reactive muffler is designed with these optimum geometrical parameters for increasing the attenuating effect. The comparison of optimized muffler with the existing muffler is shown

The peak transmission loss of both the designs were compared to assess the variation in TL and comparison is shown in fig

TL v/s length of the inter connecting tube

While analyzing the length of the interconnecting tube it is seen that as the length of the interconnecting tube increases the peak transmission loss increases and the sound can be attenuated more effectively for manufacturing the maximum length of the interconnecting tube should be 0.2m.

The below graph shows length of the interconnecting tube is 0.1875m and diameter of the interconnecting tube is 0.0275m and corresponding transmission loss is 63.5dB. Now the optimized combination of transmission loss 63.5 is Lc=0.1875m and di=0.0275m.
High transmission loss is obtained from optimized design with a difference of 7 dB. This shows that the changes in geometric parameters under the various working constraints prove to be more effective than the existing one. The optimized design have a transmission loss 25dB as compared to the existing muffler (18dB).

COMPARISON OF OPTIMIZED DESIGN WITH INSERTION OF INTERCONNECTING TUBE WITH EXISTING ONE

The effect of interconnecting tube in the existing muffler shows an increase in the TL. Length and diameter of the interconnecting tube were the two geometrical parameters that affect the transmission loss of the muffler. TL was analyzed and their geometries were optimized with respect to the optimized design for higher TL. Transmission loss of existing with an interconnecting tube and the optimized design with optimum interconnecting tube is given below.

The peak transmission loss comparison between the optimized design with interconnecting tube and existing muffler with interconnecting tube is shown in figure 7.8

The analysis results shows that, by optimizing the muffler design and varying the geometrical designs, along with the addition of the interconnecting tubes have a superior transmission loss than the existing muffler design. The optimized design with interconnecting tube has transmission loss 63 dB as compared to existing one.

CONCLUSION

The main objective of the project was to analyze the effect of the transmission loss by varying the geometrical parameters such as the length, diameter of the single expansion chamber and the outlet of the muffler. It is found that while increasing the length of the chamber the peak TL remained constant but the attenuating effect increased. Increasing the diameter of the outlet of the chamber and the outlet of the muffler the TL was increased tremendously.

The introduction of an interconnecting tube to the muffler showed an excessive increase in the transmission loss and then by varying the length and diameter of the interconnecting tube the result was an increase in the transmission loss of the muffler.

Albeit the individual variations of the parameters had effect on the transmission loss, a combination of these parameters to get the maximum transmission loss is a major concern. The optimization of these parameters was done by an optimization tool and the optimized model shows an increased TL compared to the existing one. Also the interconnecting tube with optimized diameter and length shows an tremendous increase in TL compared to the existing chamber with interconnecting tube.

It can also be concluded that GMM is a simplest and efficient method for analysing the effect of geometric parameters on TL of reactive mufflers studies can be extended to other complex geometries and the parameters can be varied and optimized to maximum attenuation using this method.

REFERENCES

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