International Journal of Research in Engineering, Science and Management
Volume-2, Issue-6, June-2019
www.ijresm.com | ISSN (Online): 2581-5792

Practically Design and Analysis of Economically Exhaust System for Automobile

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***Abstract*: This paper, discusses the design and analyzing on Exhaust system. Nowadays, numbers of vehicles come on the road per year. To design & develop an efficient and economically exhaust system for vehicle is a big challenge for engineers & researchers. Mufflers are important part of engine system and commonly used in exhaust system to minimize sound transmissions caused by exhaust gases. Design of mufflers is a complex function that affects noise characteristics, emission and fuel efficiency of engine. Therefore, muffler design becomes more and more important for noise reduction. Traditionally, muffler design has been an iterative process by trial and error. However, the theories and science that has undergone development in recent years has given a way for an engineer to cut short number of iterations. In today's competitive world market, it is important for a company to shorten product development cycle time. This paper deals with a practical approach to design, develop and test muffler particularly reactive muffler for exhaust system, which will give advantages over the conventional method with shorten product development cycle time and validation. This paper also emphasis on how modern CAE tools could be leveraged for optimizing the overall system design balancing conflicting requirements like Noise & Back pressure.**

***Keywords*: exhaust system, iterations, optimizing**

1. Introduction and Scope of the paper

An Exhaust system exhaust gas from the combustion system, removes harmful substances, reduces the level of noise and discharges the purified exhaust gases at a suitable point from its occupants. The entire system conveys burnt gases from the system and includes one or more exhaust pipes. Exhaust system is responsible for transporting the burned exhaust, or combustion gases, from its engine and out through the tail pipe Release exhaust gases depending on the overall system Design & Analysis. The exhaust system is an essential part of a combustion system and must be kept in good working order, otherwise system performance and efficiency will suffer. Significantly, the exhaust noise in terms of pressure is about 10 times all the other noises (structural noise) combined. So, the problems of reducing engine noise consist, mainly in attenuating exhaust noise. The design of mufflers has been a topic of great interest for many years and hence a great deal of understanding has been gained. Most of the advances in the theory of acoustic filters and exhaust mufflers have come about in the last four decades. Hence good design of the muffler should give the best noise reduction and offer optimum backpressure for the engine. Moreover, for a given internal configuration mufflers have to work for a broad range of engine speed. Usually when mufflers are designed by well, established numerical techniques like boundary element method or finite element method, the numerical model generation is time consuming often limiting the user to try various other possible design alternates. The process might be lengthy and laborious as it involves a more iteration with different prototypes. Mufflers have been developed over the last ninety years based on electro- acoustic analogies and experimental trial and error. Many years ago, Stewart used electro – acoustic analogies in deriving the basic theory and design of acoustic filters [1]. Later Davis et al. published results of a systematic study on mufflers [2]. They used travelling wave solutions of the one-dimensional wave equation and the assumption that the acoustic pressure P and acoustic volume velocity V are continuous at changes in cross sectional area. An important step forward in the analysis of the acoustical performance of mufflers is the application of two- port network theory with use of four pole parameters. Igarashi and his colleagues calculated the transmission characteristics of mufflers using equivalent electrical circuits [3-4]. Parrot later published results for the certain basic elements such as area expansions and contractions. Sreenath and Dr. Munjal gave expression for the attenuation of mufflers using the transfer matrix approach [5]. The expression they developed was based on the velocity ration concept. Later Dr. Munjal modified this approach to include the convective effects due to flow [6]. Young and Crocker used the finite element method to predict four-pole parameters and then the transmission loss of complex shaped mufflers for the case of no flow [7]. Ying-change, Long-Jyi used optimized approach of maximal STL and muffler dimension under space constraints throughout the graphic analysis as well as computer aided numerical assessment [8]. Middlberg J.M. and Barber T. J. present different configurations of simple expansion chamber mufflers, including extended inlet or outlet pipes and baffles have been modelled numerically using CFD in order to determine their acoustic response [9]. However, most of the research studies based on formulation of mathematical equation and trial and error method.

The scope of our work is to establish a design methodology to make design process simpler and less time consuming by making use of acoustic theories [10], [11] and experience, in short practical approach to get better design. Also, this approach will predict design quality at earlier stage of muffler design, evaluate quality of design, set targets for proto design and improves the same though out the product design steps and reduce cost of proto development.

2. Design Methodology

The properly designed muffler for any particular application should satisfy the often conflicting demands of at least five criteria simultaneously.

- The acoustic criterion, which specifies the minimum noise reduction, required from the muffler as a function of frequency. The operating conditions must be known because large steady- flow velocities or large alternating velocities (high sound pressure levels) may alter its acoustic performance.
- The aerodynamic criterion which specifies the maximum acceptable average pressure drop through the Muffler at a given temperature and mass flow.
- The geometrical criterion, which specifies the maximum allowable volume and restrictions on shape.
- The mechanical criterion, which may specify materials from which it is durable and requires little maintains.

3. Design methodology for an engine involves 7 steps

Step-1:

Target Setting and Bench Marking:

- Set basic engine input
- Bench mark engine with same
- Set target for design

Step -2:

Calculation Target Frequency

- Calculate CFR based on engine specific data
- Calculation on EFR

Step-3:

Muffler Volume Calculation

- Refer the engine basic data
- Calculate muffler volume

Step-4:

Internal Configuration and Concept Design.

- Refer benchmarking data and target frequency
- Internal configuration calculation on based on step 2
- Concept design finalization.

Step-5:

Virtual Simulation

- Refer concept design
- CFD analysis for back pressure measurement
- Virtual acoustic for TL measurement

Step-6:

Proto Type Manufacture

- Refer design from step 5
- Consider all basic
- Requirement for manufacturing

Step-7:

Experimental Testing and Design Finalization for Proto-Type.

- Calculation of TL using two sources
- Comparison of virtual simulation and experiment result.
- Finalization of best concept

4. Process of designing in brief description

Step 1: Benchmarking

The first step in any design and development activity is to set a target by doing benchmarking exercise of same kind of models. The same will be applicable for the silencer here, to set a target in terms of transmission loss of same engine power models of competitor benchmarking vehicles. Based on the provided engine input data and bench mark study target for back pressure and noise are range decided.

Step 2: Target Frequencies

After benchmarking exercise, one 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:

CFR = Engine Speed in RPM/60 for a two stroke engine (1)

= Engine Speed in RPM/120 for a four-stroke engine (2)

EFR = n × (CFR) (3)

Step 3: Muffler Volume Calculation

Based on the experience and theory of acoustics for muffler design for various engines, the following equation works well.

Volume of the muffler (Vm):

$$(Vm)= Vf\times (\pi//4(d2\times 1) \times (\text{No. of cylinders. }/2) \quad (4)$$

Now the designer needs to check packaging space that can be made available for the muffler.

Step 4: Internal configuration and concept design

Based on the benchmarking transmission loss and the target frequencies, designer draws few concepts of internal configuration that meets the packaging dimension within the volume mentioned above. Each concept and internal configuration is then formulated to the best possible configuration so as to achieve best acoustic performance and best (i.e. least) backpressure.

Perforations: Perforated pipe forms an important acoustic element of muffler, which is tuned in line with the problematic frequencies identified in step 2.

The diameter of the hole to be drilled/punched on the pipe is calculated by a thumb rule as given below:

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The diameter of the hole to be drilled / punched on the pipe is calculated by a thumb rule as given below:

$$d1 = 1.29/\sqrt{N} \quad (5)$$

Porosity: Porosity, σ is given by

$$\sigma = \frac{(\pi/4 \times d1^2)}{4} \quad (6)$$

The designer needs to keep in mind lesser the porosity more is the restriction and hence more will be the backpressure.

Open area ratio:

The open area ratio Aop is given by,

Aop = Area of perforation/Area of the plain sheet. (7)

Lesser the Aop better the transmission loss and better the acoustic performance.

At this stage, the diameter of the hole to be drilled, pitch, number of holes per row, number of rows for each pattern of holes is frozen and hence, the distance at which perforation starts and at which the perforation ends also gets frozen. Thus, the design of the perforated tube for individual hole patterns is finalized. Based on this best concept are designed and carry forward for virtual simulation.

Step 5. Virtual Simulation

Based on above mentioned approach, different concepts will be arrived with optimum combinations of different elements inside volume of the silencer. Finalized concepts will be verified virtually using CAE simulation software's towards the achievement of transmission loss and back pressure.

A. CFD Analysis

When steady air flow passes through mufflers, there will have steady pressure drop which is related to flow and geometry of air passages. Pressure drop in an exhaust muffler plays an important role for the design and development of mufflers.

Predication of pressure drop will be very useful for the design and development of muffler. To predict the pressure drop associated with the steady flow through the muffler CFD has developed over the last two decades. So, the flow prediction can be made reliable.

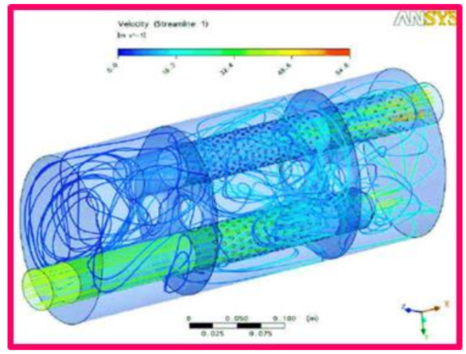

Fig. 1. CFD analysis

B. Transmission loss analysis

Prediction of transmission loss virtually is an important analysis required for the development of muffler at an

initial design stage. There are different software packages available in market for predicting the transmission loss. We have used virtual lab for Transmission loss measurements.

It is also to be noted the limitations of the CAE tools, as the co-relation at higher frequencies is difficult since the plane wave theory holds good only up to 3000Hz beyond which the wave is no more 2 dimensional but 3 dimensional for which the computations are far complex to match the practical results. Hence need of research to blend both strengths of CAE & Practical resulting in a Practical approach/methodology. After completion of simulation the best three concepts will (with less back pressure and higher transmission loss) be taken forward for the prototype manufacturing to check for the transmission loss and back pressure physically.

Step 6: Prototype Manufacturing

All the above stages combined with the packaging of the engine evolve the design of the prototype muffler and those; can be taken up for manufacturing. Following are some of the important manufacturing considerations summarized based on experience: There should not be any leakage of gas from one chamber to another. Full welding is better than stitch welding.

Acoustic performance of extruded tubes with perforations is better than the tubes that are made out of perforated and welded sheets. CEW or ERW tubes are the common materials used.

Exit her of Crimping or full welding of jacket can be used. Either of flanged or flared tubes can be used as end connections of the muffler. However, with leakage point of view, flanged connections are better. But at the same. However, with leakage point of view, flanged connections are better. But at the same time, this adds to the weight and cost of the exhaust system. Bearing all above in mind, a physical prototype is made in such a way that there will not be any tooling investment for the prototype.

Step 7: Experimental testing and design finalization

The experimental determination of backpressure on engine and transmission loss on two source method for different concepts of verified. The prototypes of all concepts that are made at the above step are tested for the transmission loss to verify the target value. The TL is the difference in sound power level between the incident wave entering and transmitted wave exciting muffler when the muffler termination is anechoic, TL is a property of the muffler only. In this work an attempt has been mad e to experimentally measure transmission loss by actually using the experimental set-up. Two source techniques give good results for the measurement of transmission loss at the different sound frequencies. Also, absence of anechoic termination, the decomposition method is found to ineffective. Therefore, we will be using two source methods in calculating transmission loss.TL values obtained from these simulations are compared with experiments.

At the same time if performance of muffler is found to be satisfactory as per engine noise requirement, then the above captured data becomes the input for further backpressure reduction. The iteration is continued usually 2 to 3 times to achieve an optimum balance between noise requirement and target of least backpressure and best fuel efficiency.

5. Inferences - Design Methodology

A brief background on evaluation of muffler concept design for the proto type and validation with new approach.

- A methodology has been developed for optimum design stages and less cost for muffler design by balancing various parameters.
- A practical tool to estimate the quality of muffler design, which used for concept selection and filter out the best concept proposal at initial phase of design.
- A practical approach for muffler design to optimization of product development time & cost by balancing conflicting requirements like Noise & Back pressure.
- Design methodology emphasis on modern CAE tools for optimization of overall system design to choose the best concept.

6. Conclusion

This paper emphasizes the importance of the design methodology –a practical approach from the concept design to proto manufacturing and validation of exhaust muffler. This design methodology will help designers in understanding the importance of each step of designing in detail from concept level to validation level. This approach serves the purpose of reducing the number of iterations, product development time and cost with better design. Although the practical approach has become an important tool in making muffler design more of art than a science, the need for design verification will always be necessary at end of each step.

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