Review Article

THERMAL ANALYSIS FOR MOTOR-BIKE EXHAUST SILENCER FOR ENSURING REDUCTION IN HOT SPOTS THROUGH DESIGN ENHANCEMENT

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ABSTRACT

The exhaust sub-system is exposed to high temperatures as they form the passage for the hot gases released upon combustion of fuel to be released to the atmosphere. While there are other prominent areas to be focused during design phase, the uniform distribution of heat over the entire exhaust system (including the silencer) is of importance for ensuing enhanced life of the elements in the sub-system. The problem identified for this proposed dissertation work is to assess the heat flow during the passage of hot gases and design the passage such as to minimize the harmful effects of hot-spots over the length of the silencer, especially at the front end mating with the exhaust manifold.

1. INTRODUCTION

Automobile Silencer is a device used to reduce the noise produced by the engine. Silencer is used in automobile vehicles to reduce the noise produced by the exhaust gases of the engine. Silencer is also used in many other engines and generators. The size, shape and construction vary according to the type and size of the engine. The primary function of the silencer is to reduce engine noise emission.

A reactive silencer generally consists of a series of resonating and expansion chambers that are designed to reduce the sound pressure level at certain frequencies. The inlet and outlet tubes are generally offset and have perforations that allow sound pulses to scatter out in numerous directions inside a chamber resulting in destructive interference. On the other hand, an absorptive or dissipative silencer uses absorption to reduce sound energy. Sound waves are reduced as their energy is converted into heat in the absorptive material. For both the types of silencers, uniform distribution of heat is desirable.

2. PROPOSED WORK/ STEPS FOR THE WORK

1. Study of design of existing silencer
2. Geometry modeling of existing silencer
3. Analysis of existing silencer for `thermal' (heat dissipation)
4. Modification in the geometry over
    a. Number of tubes within the enclosed space (of the outer shell)
    b. Perforations to the tubes
    c. Introduction of baffle/ vane obscuring linear flow thru' the passage
5. Analysis of Modified design alternatives
6. Recommendation of best suitable solution for reduction in hot-spots in the exhaust sub-system (silencer)

3. OBJECTIVES

- Reduce hot spots, especially at the mating areas/ joints near the exhaust manifold
- Improve the life of the components by reducing the incidence of uneven or non-uniform heat distribution causing mechanical failures

4. LITERATURE REVIEW

Article from orbit coating [1] they reported that the main reason behind the premature muffler failure is because of the corrosion, fatigue or combination of the both. About 80% of the failure is due to corrosion and rest is by fatigue. Some of the corrosion mechanisms affecting are as below:

- Internal corrosion due to acidic condensate.
- External corrosion due to de-icing agents used on icy roads.
- Material sensitization, especially on the hot spot (material temperatures up to 500º C for rear muffler and 600 0C for front muffler.
- (iv)Static loads due to heating and cooling cycles (low cycle fatigue).

Current Status: The material which is consistently used for the exhaust component is aluminized mild steel, stainless steel, aluminized stainless steel, ferritic chromium stainless steel. Corrosion is one of the major problems which result of high working temperature. Even Stainless Steel does not possess effective corrosion resistance due to very highly aggressive environment. The life time of a muffler is very less as compared to other parts of the automotive exhaust system. Ferritic stainless steels with a low coefficient of thermal expansion, such as AISI Types 409 and 439 should be preferred but the problem with using the ferritic grades is that they are more difficult to weld, as they are susceptible to grain growth and coarsening at welding temperatures and more prone to pitting corrosion. Aluminised mild steel is having extraordinary property to resist pitting corrosion but not suitable for high temperature corrosion and heat resistant. There by considering all the required properties to withstand the high temperature environment of automotive exhaust silencer powder coated aluminized mild steel can be used. Aluminium-plated or aluminized steel followed by powder coating has been used in the exhaust system of vehicles, for application in high temperature environments.

Comparison of aluminised powder coating with surface treated aluminised powder coating: Aluminium-plated or aluminized steel followed by powder coating is not able to resist high temperature salt damage and aqueous corrosion for longer time, but surface crystallized aluminized powder coating exhibits a corrosion resistance higher than that of the existing coating in exhaust gas condensate environment of automotive muffler and shows excellent resistance to oxidation as well with drastically improved service life.

Objective:

The main objective of the work was to develop high temperature heat resistant powder coating for mufflers of automobile applications with enhanced aqueous corrosion, high temperature corrosion which started from the generation of hot spot at front end of muffler.

Experimental set up to dry hot corrosion: the muffler split in to two parts i.e. hot end and cold end.

Cold end component test: Stage I involves the temperature in the salt spray chamber was slowly increased from ambient (±20°C) to ± 50°C while the spray was on. After an hour-and-a-half, the spray was switched off and the specimens remained in the warm, humid, salty environment for another hour-and-a-half. After the vehicle has been driven for a period, it reaches its operating temperature when the exhaust is hot and all water would evaporate — stage II. After the vehicle has stopped, the exhaust starts to cool, and since some condensation containing salt can accumulate on it, corrosion can occur again (stage III). The spray was on for one-and-a-half hours during this period. The specimens were then left overnight at ambient temperature in this humid, salty environment and ten cold-end cycles were run.

Hot end component test: During the driving cycle, the hot end components are exposed to similar conditions to the cold end components, but the temperature they reach is much higher. The simplified driving cycle designed for the hot end components was therefore identical to the cold end component tests, except for stage II. During this stage, the specimens were removed from the salt spray chamber and placed in a high temperature furnace at 900°C for three hours and hence air-cooled. For comparison purposes, an oxidation test was also conducted.

Whang jie and Dong-peng yue [2] carried out experiment in order to improve the design efficiency, resonating of the exhaust muffler should be avoided with its natural frequency. For that they selected 409L as muffler analysis material and conclude that increasing the thickness of the shell is a common to control the dynamic performance. Furthermore the noise radiation of muffler shell can be reduced by increasing the damping of shell using double plates and adding support for partition in some structure.

Method of analysis: In this paper, Pro-E software is used to create the solid model and modal analysis is carried out by use of ANSYS software to obtain the inherent low frequency vibration and vibration mode corresponding, so as to study the dynamic performance of the muffler preferably. Through setting the mode expansion, mode shape can be solved as long as obtaining each natural frequency. Reflected in the natural frequency and muffler displacement of each node may be conveniently observed and analyzed by ANSYS General Postproc, and the modal shapes could have an animation. That mode shape reflect the following observation The first 2 modal shapes, muffler swing around the rigid constraints up and down; the third mode shape swing twisted around the rigid constraints; the forth mode shape stretches before and after exercise around the rigid constraints; The fifth modal shape is stretching before and after exercise of export control and partitions with inlet tube bending movement; the sixth modal shape is about the overall bending motion. Through the comparison between constraint modal frequency and external excitation frequency of the muffler, the vibration parameter can be known and whether there is resonance can be judged. By this the optimal direction of muffler can be determined.

The engine exhaust excitation frequency f=in / 30T, where i is the number of cylinders, n is engine crank speed, T is the number of engine stroke. The muffler exhaust incentive is away from the inherent frequency, to avoid the occurrence of resonance.

Aminudin Abu Faculty of Mechanical Engineering [3] This paper is the first stage in the design analysis of an exhaust system. With the specified properties of the material, the exhaust system is modeled by using a conventional FEM package, MSCINASTRAN. The results are compared to the one developed by Transfer Matrix Method. The hanger location of the exhaust system is determined by estimation of the normal mode of the total exhaust system.

The noise might have a different type of characteristic of vibration modes affected by idle shake and interior noise of the vehicle. Normally, the engine vibrations are transmitted to the exhaust pipe and they are divided into two categories; first, longitudinal vibration and second bending vibration. Both categories must be taken into account for noise and vibration analysis.

Methodology: In addition, the analysis is performed in MSC/NASTRAN, by using the solver processor's Lanczos Modal Extraction Method. The method is selected because stiffness and mass matrices are easily extracted and is more useful for forced vibration analysis.The present study emphasizes on free and one end fixed vibration analysis in determining the natural frequencies and the characteristics of the system. The desired natural frequency was investigated together with the mode shape. Those obtained frequencies are referred and the lowest mode is identified as a predicted hanger location. During the analysis procedure, power plant is not considered. The mode analysis is performed below 200 Hz based on the 2nd order component of a cylinder engine.

A. Mimani, M.L.Munjal [4] reported that Short elliptical chamber mufflers are used often in the modern day automotive exhaust systems. The acoustic analysis of such short chamber mufflers is facilitated by considering a transverse plane wave propagation model along the major axis up to the low frequency limit. The one dimensional differential equation governing the transverse plane wave propagation in such short chambers is solved using the segmentation approaches which are inherently numerical schemes, wherein the transfer matrix relating the upstream state variables to the downstream variables is obtained. This present work is thus an attempt to fill up this lacuna, whereby Frobenius solution of the differential equation governing the transverse plane wave propagation is obtained. By taking a sufficient number of terms of the infinite series, an approximate analytical solution so obtained shows good convergence up to about 1300 Hz and also covers most of the range of muffler dimensions used in practice. In this paper by using Frobenius solution of transverse plane wave equation Derivation of transfer matrices for different muffler configurations are generated they are as follows.

1. A short elliptical chamber having a side inlet and side outlet port.
2. A short elliptical chamber having a side inlet and

a) End outlet port on the same half as the side inlet port.
b) End outlet port on the opposite half of the side port.

3. A short elliptical chamber having an end inlet and end outlet port with both the ports located
   a) On the same half
   b) On the opposite halves.

Validation of the Frobenius solution is did by using following method or comparisons with other author method.

1. Comparison against the Matrizant approach.
2. Elliptical end chamber mufflers analyzed by Young and Crocker.
3. Elliptical chamber mufflers with end-central inlet and side outlet analyzed by Selamet.
4. Elliptical chamber mufflers analyzed by Denia et al.
5. Short circular expansion chambers with side inlet/outlet analyzed by Selamet & Ji.

It is indeed observed that this analytical approach is much faster than the Matrizant approach as the present method obtains solution in the form of a truncated polynomial series, which are very quick to evaluate. In fact, this method is particularly suited for the analysis of a short elliptical chamber with more than two ports, i.e. for a multi-port system.

S.N. Panigrahi and M.L. Munjal [5] reported that a code based on the developed algorithm has been employed to demonstrate the generality of the proposed method in analyzing commercial mufflers by considering three very diverse classes of mufflers with different kinds of combinations of reactive, perforated and absorptive elements. Though the examples used in the paper are not very complex for they are meant to be just representative cases of certain classes of mufflers, yet the algorithm can handle a large domain of commercial mufflers of high degree of complexity. Results from the present algorithm have been validated through comparisons with both the analytical (plane wave based) and the more general, three-dimensional FEM based results.

Takashi Yasuda, Chaoqun Wua, Noritoshi Nakagawa, Kazuteru Nagamura [6] studied the tail pipe noise from a commercial automotive muffler by experimentally and numerically method under the condition of wide open throttle acceleration. The engine was accelerated from 1000 to 6000 rpm in 30 s at the warm up condition. The transient acoustic characteristics of its exhaust muffler were predicted using one dimensional computational fluid dynamics. To validate the results of the simulation, the transient acoustic characteristics of the exhaust muffler were measured in an anechoic chamber according to the Japanese Standard (JIS D 1616). It was found that the results of simulation are in good agreement with experimental results at the 2nd order of the engine rotational frequency. At the high order of engine speed, differences between the computational and experimental results exist in the high revolution range (from 5000 to 6000 rpm at the 4th order, and from 4200 to 6000 rpm at the 6th order). According to these results, the differences were caused by the flow noise which was not considered in the simulation. The purpose of the present paper is to study the transient acoustic performance of a typical commercial muffler using one dimensional CFD and experimental method, and then develop a simplified model with acceptable accuracy to meet the demand of time to market in the optimization design.

C.J. Wu, X.J. Wang, H.B. Tang [7] studied the acoustical performance prediction on single-inlet/double-outlet (SIDO) and double-inlet/single-outlet (DISO) expansion-chamber mufflers with rectangular section. Expressions for the transmission loss (TL) of this kind of mufflers are formulated by using the collocation approach. Numerical results of TL are compared with the plane wave theory to show up the higher-order mode effects. Furthermore, the finite element method (FEM) is also employed again to verify its accuracy in view of these configurations of muffler.

Min-Chie Chiua, Ying-Chun Chang [8] used the four-pole system matrix for evaluating acoustic performance is derived by using the decoupled numerical method. Moreover, a simulated annealing (SA) algorithm, a robust scheme in searching for the global optimum by imitating the softening process of metal, has been adopted during shape optimization. To reassure SA's correctness, the STL's maximization of three kinds of muffles with respect to one-tone and dual-tone noise is exemplified. Furthermore, the optimization of mufflers with respect to an octave-band fan noise by the simulated algorithm has been introduced and fully discussed. Before the SA operation can be carried out, an accuracy check of the mathematical model with respect to cross flow perforated mufflers has to be performed by Munjal's analytical data and experimental data.

J. Albelda, F.D. Denia, M.I. Torres, F.J. Fuenmayor [9] they has presented a new modal method to calculate the acoustic behaviour of perforated dissipative mufflers involving ducts with arbitrary (but axially uniform) cross-section. First, the different cross-sections have been divided into disjoint subdomains. Two modal bases have been considered for each subdomain, associated with zero normal velocity and zero pressure boundary conditions at the interface between subdomains of the same cross-section. Then, the complete transversal modes have been evaluated by component mode synthesis. Finally, the mode matching method has been applied at the geometrical discontinuities to calculate the global acoustic behavior of the muffler. The proposed methodology has been validated by comparison with three-dimensional finite element calculations. In addition, the procedure has been used for the analysis of the acoustic attenuation performance of a perforated dissipative elliptical resonator with offset extended inlet and outlet.

5. METHODOLOGY:-

1) Mathematical Method

For the problem to be diagnosed, the empirical formulae in the Engineering domain can be applied for seeking a solution. The study over the subject done in the past has offered formulae derived by the researchers in the respective field. Application of the relevant mathematical rule to the problem at hand can lend a credible solution for finding the best alternative. Typically, the formulae in the field of Applied Mechanics or Structures can be helpful for finding a numerical value for specifying the quantum of the unit or direction for the solution.

2) Analytical Method

Analytical methods refer to techniques and procedures for analyzing data collected while conducting an evaluation. Two main types of analytical methods include qualitative and quantitative procedures. Quantitative methods include statistical techniques for analyzing data, and qualitative methods analyze information, such as notes from interviews and observations, that cannot easily be summarized in numerical terms.

Popular quantitative methods used in evaluation include, but are not limited to, analysis of variance, factor analysis and linear regression. Quantitative methods make data easier to analyze and summarize, and qualitative approaches are subject to varying interpretations. Many evaluations, especially in education and the social sciences, combine qualitative and quantitative techniques. Typically, Statistical tools are engaged like ANOVA, DOE or other process control or parameter optimization techniques. Typically, the software MiniTab is utilized for working on these tools.

3) Computational approach

This presents a computational approach for the assessment of the given problem. One of the main features of the work is the search for simplicity and robustness in all steps of the modeling, in order to match the proposed method with industrial practices and constraints. The proposed method utilizes software in the domain of FEA (Finite Element Analysis) for analyzing the effects of the variation in the values of the design parameters influencing the response parameter. For our case, a suitable CAE software in the structural domain like Nastran/ Ansys/ Abaqus/ RadioSS or similar solver would be deployed.

4) Experimental set up

With the use of experimental set-up we can analyze the data in a real time environment or verify the actual results obtained by other methods. This method is simpler to visualize and understand but is more challenging in terms of manipulation of the input data for finding the sensitivity associated with the output. Also, it is time consuming and expensive to build a prototype and later engage the testing equipments for this purpose. For our case, for reasons of confidentiality, the Sponsoring Company would only provide experimental and validation data generated at its end. This data can be utilized for comparison with the Analytical approach or the Mathematical treatment offered to the thesis work.

Of the above, the computational approach using CAE software would be administered for this proposed work. The methodology for Physical experimentation would be deployed for verifying the results so obtained.

6. EXPERIMENTATION

The two-wheeler identified for this case being a recent variant introduced by a top OEM in this segment, the experimentation would be performed over the silencer of a `live' vehicle. For the existing silencer, the readings for temperature would be recorded at various designated locations over the entire length of the silencer. This data would be compared with the benchmark analysis done using the `existing' i.e. current geometry for the silencer. A good concurrence of the readings would be a precursor for alignment of readings over the `modified' geometry to be suggested later for meeting the objectives.

7. VALIDATION

Comparison of the data determined by `analysis' i.e. the computational approach/ methodology with the physical (laboratory) experimentation would be a good pointer to validate the design. The design would be said to be validated if the geometry of the silencer yields a result that displays a good match within the analysis and the physical experimentation.

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