

Analysis of Exhaust Muffler In Internal Combustion Engine Using finite Element Method

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Abstract- Internal combustion engines have been playing a vital role and will remain an active area of engineering education and research in future. Most of the researches in internal combustion engines are of operating performance and fuel performance improvement oriented. Almost all the components in an internal combustion engine are subjected to heat loads. The current study attempt has been made to simulate the physical working conditions of components of an internal combustion engine. The analysis is virtual simulation (because it was carried out with the help of a digital computer and a software tool-ANSYS 17). The current study emphasizes on stress, strain, temperature, heat flux, thermal gradient distributions in the component Exhaust muffler materials. CREO was used for the solid modeling of engine components and ANSYS 17 was used for the analysis. The study was carried out on prime components of an internal combustion engine such as Exhaust Muffler. Exhaust muffler were subjected to study heat and fluid flow loads.

Key words- FEM, Exhaust Muffler, ANSYS 17, Peak load Moment simulation.

I. INTRODUCTION

The internal combustion engine had developed in the late 1800s. It had significant impact on society, and was considered one of the most significant inventions of the last century. The internal combustion engine had been the foundation for the successful development of many commercial technologies. Internal combustion engine power is in the range from 0.01 kW to 20×10^3 kW depending on its piston displacement. These engines compete in the market with electric motors, gas turbines, and steam turbines. The major applications are in the vehicular world (automobiles and truck), railways, marine, aircraft, home use, and stationary. The majority of internal combustion engines are produced for vehicular applications, which require a power output of 10^2 kW. Internal combustion engines have become the prime power technology in many areas.

The first internal combustion engine had used the reciprocating piston-cylinder principle in which a piston oscillated back and forth in a cylinder and transmitted power to a drive shaft through a connecting rod, it worked on crankshaft mechanism. Valves were used to control the flow of gas in and out of the engine. The components of a reciprocating internal combustion engine, block, piston, valves, crankshafts, and connecting rod, had remained unchanged since the late 1800s. The main difference between a modern-day engine and one-built 100 years ago is thermal efficiency and the emission level (A. R. Bhagat, 2012). For many years, the internal combustion engine research was aimed at improving thermal efficiency, reducing noise and vibration. Therefore, the thermal efficiency had increased from about 10% to values as high as 50%. Since 1970, with the recognition of the importance of air quality, there have also been a great deal

of work devoted to reducing emissions from engines. Currently, the emissions control level requirement is one of the major factors in the design and operation of internal combustion engines.

Diesel engine has been the prime mover for all commercial purposes for so long. The compression ratio of the petrol engine is between 6 and 10 while for a diesel engine it is from 16 and 20 (Ganesan, 2012). The diesel engine is also called as explosion engine as the nature of combustion is explosion of diesel fuel. Diesel engine is a dirty and smoky engine. It is very rigid in construction as the burning pressures, and temperatures are typically high. The inlet air in the diesel engine is unthrottled. The power is controlled by the amount of fuel-air injected into the cylinder. In order to ignite the fuel-air mixture, diesel engines are required to operate at a higher compression ratio, resulting in a higher theoretical thermal efficiency as compared to the spark ignition engine.

The power output (Braking Power) of the diesel engine depends upon displacement volume, which decides the amount of fuel that can be burned completely. In order to burn the fuel molecules completely, sufficient amount of air must be sucked in, otherwise, there is no meaning of injecting large quantity of fuel. Diesel engines are being designed in various sizes for different applications. The power output of the diesel engine depends on displacement volume of the engine. The more the displacement volume the more is the amount of burning and hence more power output. Peak pressure and temperature in a diesel engine cycle depends on amount of burning. Diesel engines are normally of four-to-six-cylinder engines. (Engine size is directly proportional motive power needed.) Diesel engines normally, burn large quantity of fuel and air as they are primarily used in

commercial utility vehicles such as buses, trucks, lorries, ships and locomotives etc. Diesel engines are normally multi cylinder types because the power output is the prime aim rather than emissions norms. As shown in figure.

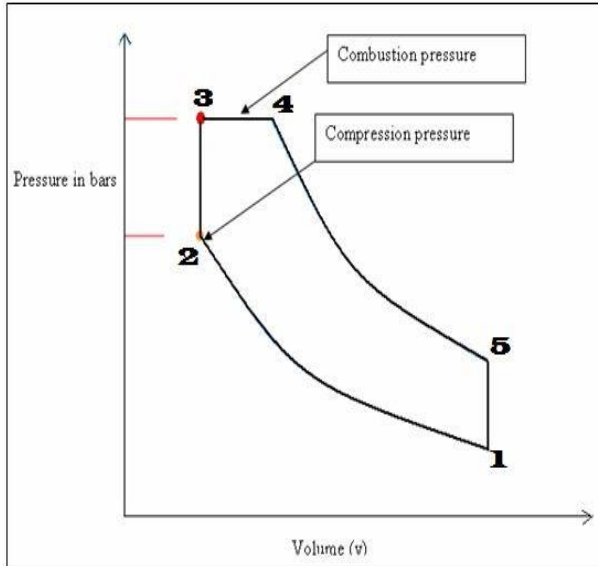


Figure 1 Pressure-Volume Diagram

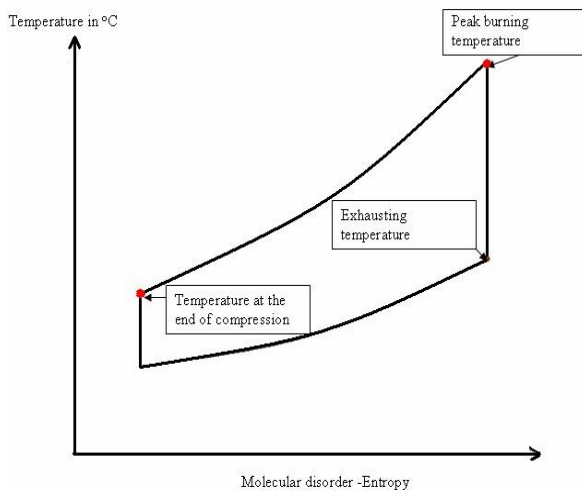


Figure 2 Temperature-Entropy Diagram

Typical diesel engine combustion cycles, Pressure-crank angle plots and temperature crank angle plots. But each material element that we find in this universe has some melting point and strength. Internal combustion engine components are designed for a particular amount of peak load and temperature. When the operating pressure and temperature exceed the designed limit then the failure of the engine component is not due to inadequate design consideration. Therefore, the peak combustion pressure and temperature are design parameters. Higher the combustion pressure, the greater is the number of stresses on the engine components. Piston and engine block is subjected to both structural and thermal loads. Exhaust and intake manifold are subjected to heat and fluid flow loads.

Internal combustion engines at best can transform about 25 to 35 percent of the chemical energy in the fuel into mechanical energy (Assanis and Min Chun, 1999). About 35 percent of the heat generated is lost to the cooling medium, remaining heat dissipated through exhaust and lubricating oil.

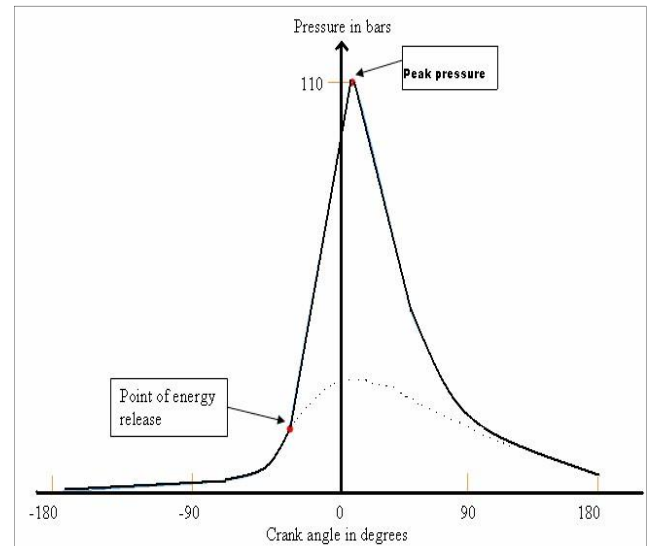


Figure 3 Pressure-crank angle plots

During the process of combustion, the cylinder gas temperature often reaches a high value. A considerable amount of heat is transferred to the walls of the combustion chamber. Therefore, it is necessary to provide proper cooling especially to the walls of the combustion chamber. Due to prevailing high temperatures, the change in chemical and physical of the lubricating oil may occur. This causes wear and sticking of the piston rings. Excessive cylinder wall temperatures therefore, will raise the operating temperature of the piston head. This in turn will affect the strength of piston seriously. In addition, the overheated cylinder head may lead to overheated spark plug and electrodes causing pre-ignition. The exhaust valve may become overheated hot to cause pre-ignition or may fail structurally.

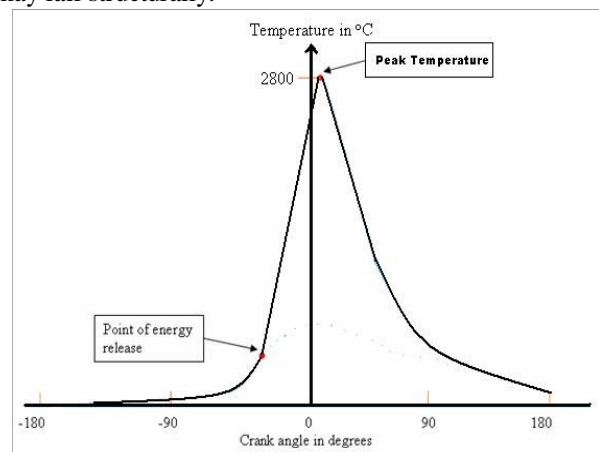


Figure 4 Temperature Crank Angle Plots

II. LITERATURE REVIEW

Bishop, Empirical equations which describe, individually, the magnitude of the most important factors determining the cycle efficiency and motoring friction of an engine are derived from experimental data. These equations are organized into a computational procedure which recognizes the interdependence of these factors and provides a method for estimating the overall efficiency of any given engine.

D. Lancaster et al, This paper provides a user-oriented description of techniques for the measurement and analysis of engine cylinder pressures. These techniques were developed for piezoelectric transducers and for digital systems of data acquisition and analysis. Test cell procedures are described for transducer preparation and calibration, and for association of each pressure with its appropriate crank angle. Techniques are also described for evaluating the accuracy of pressure data and for eliminating specific errors. Two examples of uses for pressure data are discussed: the calculation of heat release rate in conventional engines, and the computation of internal flows in divided chamber engines.

J. Blech, The problem of engine head thermal stresses which may cause its cracking is discussed in both quantitative terms and in the methods of crack circumvention. It is pointed out that in the present state of the art only scarce knowledge exists on thermal boundary conditions in both the combustion chamber and in the coolant side. Effective relieving schemes include cylinders decoupling and introduction of thermal barriers. The need is pointed out for further research in augmentation of heat transfer schemes on the coolant side.

M. Groeneweg, The drive to increase engineering productivity and decrease expensive hardware testing has resulted in the widespread application of the finite element method of structural analysis to diesel engine components. The scope of finite element analysis at Detroit Diesel Allison has been expanded far beyond the simple investigation of mechanically induced component stresses. The DDA developed, multipurpose finite element code, STRATA, has been used to analyze critical deflections, combustion induced thermal stresses, the probability of survival of ceramic structures and assembly parameters for ceramic-metal composite components.

S. Bohac, et. al, A global, systems-level model which characterizes the thermal behavior of internal combustion engines is described in this paper. Based on resistor-capacitor thermal networks, either steady-state or transient thermal simulations can be performed. A two-zone, quasi-dimensional spark-ignition engine simulation is used to determine in-cylinder gas temperature and

convection coefficients. Simulation sub-models and overall system predictions are validated with data from two spark ignition engines. Several sensitivity studies are performed to determine the most significant heat transfer paths within the engine and exhaust system.

K. Lee, K. Assanis et al, The combined experimental and analytical approach was followed in this experimental research work to study stress distributions and causes of failure in diesel cylinder heads under steady-state and transient operation. Experimental studies were conducted first to measure temperatures, heat fluxes and stresses under a series of steady-state operating conditions. Subsequently, a finite element analysis was conducted to predict the detailed steady-state temperature and stress distributions within the cylinder head.

C. Ciesla, R. Keribar, et al, Engine and vehicle development is a multi-step process: from component design, to system integration, to system control. There is a multitude of tools that are currently being used in the industry for these purposes. They include detailed simulations for component design on one hand, and simplified models for system and control applications on the other hand. This introduces one basic problem: these tools are almost totally disconnected, with attendant loss of accuracy and productivity.

M. R. Ayatollahi, In this study, finite element analysis was carried out on a diesel engine piston, in order to attain its high cycle fatigue (HCF) safety factor and low cycle fatigue (LCF) life. In order to calculate the HCF safety factor, a macro was developed using ANSYS 17 Parametric Design Language (APDL). High cycle fatigue generally contains elastic cyclic behavior, high frequency, low strain amplitude and large number of cycles to failure. The results showed that the regions around piston oil inlet hole and the piston and piston pin contact region are the most critical regions, mainly due to high mean and alternating stresses caused by cyclic loads. After considering the stress gradient effects.

M Y E Selim, Experimental investigation was carried out to evaluate the heat transfer performance of three engine coolants and their mixtures with distilled water under real engine conditions. The coolants and their mixtures with water were used in a single-cylinder diesel engine running on gasoil fuel. Heat flux and wall temperatures were measured in the critical areas of the cylinder liner and cylinder head using traverse thermocouple probes. Coolant performance was defined as the ability to maintain a lower wall temperature for a given heat flux. Test parameters included coolant concentration in distilled water, engine load (heat flux).

D.D Wickman, Design fitness was determined using a modified version of the KIVA-3V code, which calculates the spray, combustion, and emissions formation processes. The simultaneous minimization of these factors was the goal. The KIVA-GA methodology

was used to optimize the engine performance using nine input variables simultaneously. Three chamber geometry related variables were used along with six other variables, which were thought to have significant interaction with the chamber geometry. Both engines were optimized at a medium-speed, high-load condition with a similar global equivalence ratio.

J Draper, G Malton. Fatigue analysis methodology is evolving continuously, particularly in the area of multi axial fatigue. However, existing algorithms carefully implemented allow complex multi axial stress states to be analyzed successfully. Analysis of elastic FEM results, with the elastic-plastic conversion built in to the fatigue software, provides a computationally-efficient method of processing fatigue loading sequences. Examples of the fatigue analysis of diesel pistons have demonstrated that this method can predict crack initiation sites and fatigue lives to a very acceptable level of accuracy. At higher temperatures time-dependent phenomena must be taken into account.

Objectives

The work addresses the requirement of a piston industry. It emphasizes on the productivity improvement of the piston materials. Due to its industry relevant nature & various types of mufflers and silencers, their effects were studied along with their performance parameters. The focus of this is to review the most relevant research that has been undertaken in the area of passive mufflers and optimization methods. Following are objectives for my research work:

- To study the functioning of design and analysis of Exhaust Muffler of IC engine.
- To study the publications done by various researchers based on their experimental or theoretical research work and find the gap to formulate the problem.
- To study the methodology followed by researchers for design and analysis to find the solution of the formulated problem.

III.METHODOLOGY

Finite element method is a numerical procedure for analyzing structures and continuum. Continuum is nothing but physical domain to be analyzed. Usually, problem addressed is too complicated to be solved by classical methods (B. Bathe. 2007). The problem may concern stress analysis, heat conduction, or any of several other areas. The finite element method procedure produces many simultaneous algebraic equations, which are generated and solved on a digital computer. Finite element analysis calculations are performed on personal computers, mainframes, and all sizes in between. Results are rarely exact. The finite element method originated as a method of stress analysis. Today finite elements analysis is used to analyze problems of heat transfer, fluid flow,

lubrication, electric and magnetic fields, and many others. Finite element procedures are used in the design of buildings, electric motors, heat engines, ships, air frames, and spacecraft. Manufacturing companies and large design offices typically have one or more large finite element programs in-house. The classical approach is to write the differential equation of the continuously tapered bar, solve this equation for axial displacement u as a function of x , and finally substitute $x = LT$ to find the required displacement (Daryl Logan, 2007). The finite element approach to this problem does not begin with differential equation. Instead, the bar is divided by modeling it as a series of *finite* elements, each uniform but of a different cross sectional area A . In each element, u varies linearly with x ; therefore, u is a piece wise smooth function of x . Model built of four uniform elements of equal length as shown in figure.

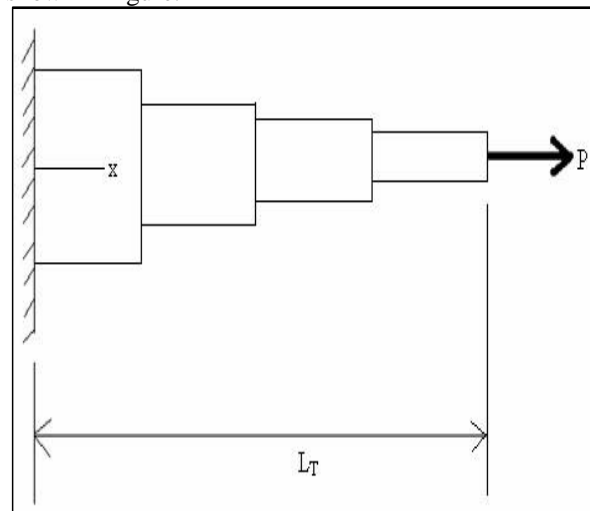


Figure 5 Model built of four uniform elements of equal length

The elongation of each element can be determined from the elementary formula

$$\text{Element deformation} = \frac{PL}{AE}$$

Where P = load applied in N, L = Length of a small element in m.

A = cross-sectional area of an element in m^2

E = Modulus of elasticity (stiffness of the material) in N/m

The end displacement, at $x = LT$ is sum of the element elongations. Accuracy improves as more elements are used. In the foregoing discussion finite element method models a structure as an assemblage of small parts (elements). Each element is a simple geometry and therefore, is much easier to analyze than the actual structure. In essence, we approximate a complicated solution by a model that consists of piecewise-continuous simple solutions.

Procedure of Finite element method

1. Divide the structure or continuum into finite elements. Mesh generation programs, called preprocessor, help the user in doing this work.
2. Formulate the properties of each element
3. Assemble the elements to obtain the finite element model of the structure.
4. Apply known loads: apply known loads and/or moments in stress analysis, nodal heat fluxes, convection loads in heat transfer.
5. In stress analysis, specify that the structure is supported. This step involves setting several nodal displacements to known values (which often are zero). In heat transfer analyses, typically certain temperatures are known, impose all known values of nodal temperature.
6. Solve simultaneous linear algebraic equations to determine nodal degree of freedom (nodal displacements in stress analysis, nodal temperatures in heat transfer).
7. In stress analysis, calculate element strains from the nodal displacements and finally calculate stresses from strains. In heat transfer analysis, calculate element heat fluxes from the nodal temperatures. Output interpretation programs, called post processors, help the user sort the output and display in graphical form.

IV. RESULTS

Muffler is a fluid flow device, which is used in internal combustion engine to reduce the pressure and sound of the exhaust flow products by passing the exhaust products through so many flow obstacles, which reduces the pressure pulsations, and sound energy of the exhaust products. If muffler were not in place, then there would be a strong pressure pulsation, which induces the sound. In one way, muffler acts as a damper for pressure and sound (S. D Hires and G.L Pochmara, 1979). The sound energy of the exhaust products is reduced by providing obstacles, which the combustion products have to overcome there by losing its energy. Therefore, the velocity and pressure of the combustion products are important parameter as they strongly affect the pressure pulsations. These velocity and pressure profiles are, normally, obtained by carrying out the CFD analysis. Hence, CFD analysis was carried out and velocity and pressure profiles are obtained. The typical diesel engine Exhaust mufflers is shown in figure 6.



Figure 6. Exhaust mufflers

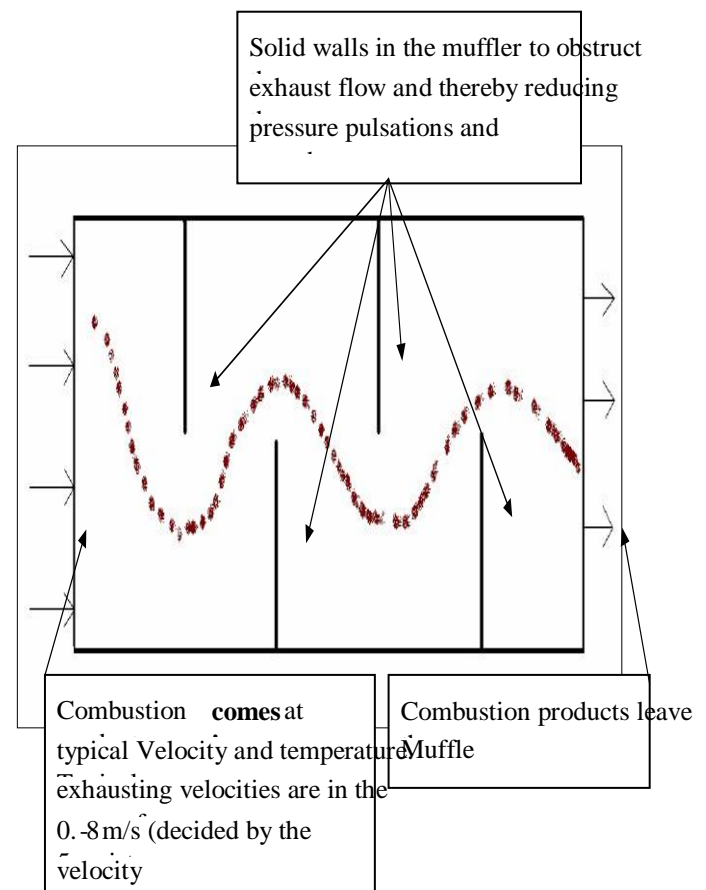


Figure 7 Statement of the physical problem

The combustion products flow through the muffler (Mohd Sajid Ahmed, 2015). Muffler is a very complicated geometry as it has number baffle plates to obstruct the combustion products and there by removing the pressure and sound energy. When combustion products pass through this complex geometry, sound and pressure energies are dissipated there by letting the combustion

product with no pressure pulsations. The physical problem in hand is very complex as two physical phenomena's (sound and flow energies) are involved in it. The typical velocity of the combustion products at the inlet is in the range of 0.5-8 m/s, which is decided by the piston velocity and exhausting pressure. The physical problem is shown in figure 7.

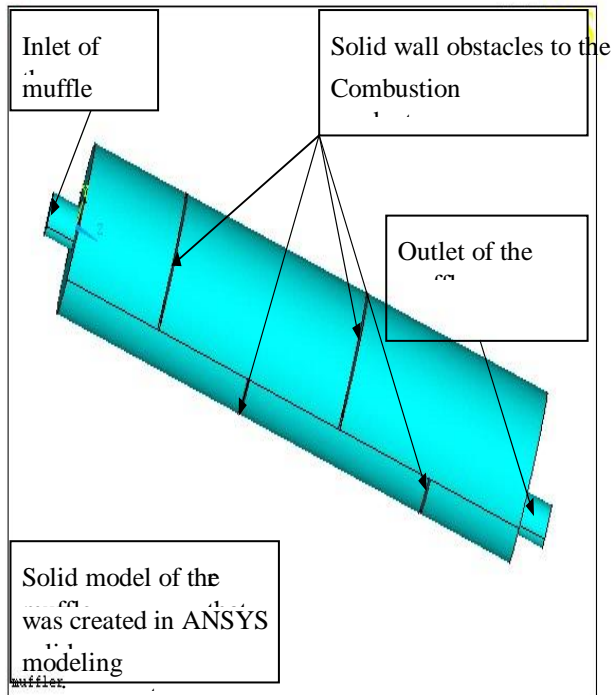


Figure 8 Solid model of the muffler created in ANSYS 17 solid modeling environment

V.CONCLUSION

The inlet area of the muffler receives the combustion products and outlet area of the muffler lets the combustion products to leave the muffler. All the outer surfaces and front faces except the inlet and outlet areas are specified as boundary walls and atmospheric pressure was applied on the outlet area.

After applying the boundary, the problem was solved by the ANSYS 17 Solver. ANSYS 17 solver formulates the governing fluid equations for each element and those formulated governing equations were solved for the pressures and velocities. it is very interesting to note that the first solid wall, directly impacts combustion products come into the muffler, and then moves down; again, it encounters the next obstacle and takes an upward flow and then combustion products were forced to flow towards outlet by the circumference walls. This is the combustion products flow through the muffler.

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