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A Review Paper on Finite Element Analysis of Piston of An Internal Combustion Engine Using Simulation Technique

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A B S T R A C T

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 of the components in an internal combustion engine are subjected to heat loads. 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 Piston, Engine block and Exhaust muffler materials. CREO was used for the solid modeling of engine components and ANSYS 17 was used for the analysis. Peak stress, deformation and temperature profiles were a matter of concern when analysis carried out in piston, engine block, and exhaust muffler. Velocity, temperature, and pressure distributions are a matter of concern when analysis carried out.

Keywords: FEM, Piston, Engine Block and Exhaust Muffler, ANSYS 17, Peak load Moment simulation

1. 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.

1.2 Research Significance

In the current study an attempt has been made to analyze the prime components (piston, engine block and exhaust muffler) of an internal combustion engine using Finite Element Analysis. Static stress analysis and steady-state heat transfer analysis were performed on piston and engine block. Computational fluid flow analysis was performed on exhaust manifold and exhaust muffler. All the above analyses were carried out with the help of CREO and ANSYS 17. CREO is a solid modeling tool. Since “Finite Element Method” procedure needs solid of the component to be analyzed, solid modeling of prime components was done in CREO. ANSYS 17 is basically an analyzing system, with which any physical working condition can be simulated virtually. The very basic intention is to simulate the working conditions of the engine components virtually for different loading conditions, for different component geometries, and for different component materials. Analysis is concerned with diesel engines and their design aspects.

1.3 Research objective

1. To study the functioning of design and analysis of Piston, Engine block, Exhaust Muffler of IC engine.

2. To study the publications done by various researchers based on their experimental or theoretical research work and find the gap to formulate the problem.

3. To study the methodology followed by researchers for design and analysis to find the solution of the formulated problem.

4. To study temperature in the piston when there is no cooling mediums such water and oil. To study peak surface temperature in the piston when cooling mechanism is simulated (Convection water and oil cooling)

2. LITERATURE REVIEW

I. Bishop, (2022). 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. A mathematical experiment using this analytical method is described. The results of this experiment are presented to show the overall effect of these factors when varied individually or in combinations on a hypothetical engine.

D. Lancaster et al, (2021). 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, (2021). 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, (2019). 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. Finite element analysis has also been combined with the concept of factorial experiments to optimize new component designs. Specific examples of each application are discussed including piston kit, cylinder head, and valve gear components. Analytical results are interpreted and unique characteristics highlighted.

S. Bohac, et. al, (2017). 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. Overall, it has been shown that the model is a powerful tool in predicting steady-state heat rejection and component temperatures, as well as transient component temperatures.

K. Lee, K. Assanis et al, (1999). 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. A comparison of the predicted steady-state temperatures and stresses were done well with their measurements. Additionally, the predicted location of the crack initiation point correlated well with experimental observations. This suggested that a validated steady-state FEM stress analysis can play a very effective role in the rapid prototyping of cast-iron cylinder heads.

C. Ciesla, R. Keribar, et al, (2014). 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, (2016). 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, the HCF safety factor improved by 15% in the oil inlet hole and 50% in the pressure rings region. The regions around the oil inlet hole in piston skirt are the critical regions from the LCF life point of view. This was studied using FEM method by the authors. This peak combustion pressure induces the compression stress in the piston.

M Y E Selim, (2015). 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), coolant flow rate and coolant type under forced convection and sub cooled boiling conditions. Results showed that the coolant performance is critically affected by the coolant constituents, heat flux transferred and flow velocity.

D.D Wickman, (2001). 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 ultimate 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. Another benefit is that input data (as well as calculated results) are easily transferable among the different groups of the design team (engine, powertrain, system, control), because these groups can share a single tool.

J Draper, G Malton, (2002). 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. Four such phenomena strain rate and instantaneous temperature, the phase relationship between stress and temperature, bulk stress relaxation, and pre-soak/strain ageing have been included in fatigue analysis software.

Qin Yin Fan, (2004). Author focused on how to use a steady state temperature result obtained by a CFD analysis to conduct a thermal-stress analysis easily with 3 data transfer methods (Direct Conversion Method, Surface Mapping Method and Volume Mapping Method). The advantage and disadvantage of the 3 methods were compared in that paper and a steady state analysis of an engine exhaust manifold was used to show the accuracy, flexibility, efficiency and practicality. It is of great significance to simplify all these operations by preparing an input file as explained in the following paragraphs. Furthermore, author shows how to choose a few steps of transient temperature results as the loads of thermal stress analysis from a long list of CFD transient results to estimate the local maximum transient thermal stress. In this paper a T pipe and an exhaust manifold are used to describe simplification of data transfer procedures.

3. Problem formulation

These are the reasons that necessitate conducting FEA analysis on piston and engine block.

- To check whether or not piston and engine block takes the structural stress induced due to gas load.
- To check whether or not piston and engine block material takes the heat load (fuel energy released at the point of combustion).
- To check thermal stress are severe.

Is piston and engine block geometry optimized enough to take the loads.

Temperature, heat flux and stress measurements were acquired on a six-cylinder, naturally- aspirated, direct-injection, TATA diesel engine at ICAT, primarily used in bus applications. Analytical approach was followed in this work to study stress distributions and causes of failure in diesel Piston and engine block under steady state and transient operation. Analytical studies were conducted first to measure temperatures, heat fluxes and stresses under a series of steady-state and transient operating conditions at ICAT. Finite element analysis was conducted to predict the detailed steady-state temperature and stress distributions within the Piston, engine block. The primary specifications of the engine are reported below.

Specifications of engine For TATA 1210D truck Manufacturer : Tata Motors, India

Engine model & type : 1210DI diesel engine, 6-cylinder, in line Bore : 92 mm

Stroke : 120 mm

Capacity : 7545 C.C.

Compression ratio : 17.5

Ignition Order : 1-5-3-6-2-4

Maximum Torque : 475 N·m @1500 rpm

Maximum Power : 123 kW @ 2200 rpm

4. CONCLUSION

• The current study emphasis on stress, strain, temperature, heat flux, thermal gradient, velocity and pressure distributions in the component materials. The study was carried out using the Finite Element Methods Approach. The type of study is peak moment simulation which means that only the conditions prevailing at the point of combustion are simulated.

All the analyses were carried out for different boundary conditions, different geometries and different materials properties.

1. The peak surface temperature of the piston material when there is no cooling is about 1980oC against 518oC when cooling was provided in aluminium piston. Peak stress was in the piston due to combustion pressure= 118 N/mm2

5. SCOPE FOR FUTURE WORK

Since analyses carried were of “Steady state structural and thermal peak moment simulation” type, Steady state structural and thermal peak working conditions were simulated to observe geometry, material. But internal combustion engines components are subjected to varying heat and pressure loads in the cylinder throughout the cycle. Therefore, the peak moment simulation is certainly not adequate to predict the real working conditions of the engine components.

1. Dynamic and transient heat transfer analysis can be performed on piston and engine block to predict the real working conditions of the components.

2. Buckling and fatigue analysis can be performed on connecting rod.

3. Similarly, the exhaust manifold and exhaust muffler are subjected to continuous flow and thermal loads.

4. Hence, the transient heat and turbulent flow analysis can be conducted on these combustion product flow devices. This FEM study can be extended to engine valves, heads, bearing analysis, and fuel injection systems etc.

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