Engineering Universe for Scientific Research and Management
ISSN (Online): 2319-3069
Vol. XV Issue IX
Sep 2023

A Review on simulation and modelling of Engine block to enhance the characteristics of I.C. engine by using finite element analysis

Mr. Sachin Baraskar[1], Saif Ali[2]
Assistant Professor, Mechanical Department, SSSUTMS, Sehore, M.P., India[1]
Research Scholar, Mechanical Department, SSSUTMS, Sehore, M.P., India[2]

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 of the components in an internal combustion engine are subjected to heat loads. Every mechanical component Engine block, Exhaust muffler have been designed for a particular structural and heat strength. Cylinder block melting are typical problems when heat and structural loads on the components exceed the design strength. In 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 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.

Keywords: FEM, Engine Block and 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 20×103 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 102 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 . For many years, the internal combustion engine research were aimed at improving thermal efficiency, reducing noise and vibration. As a consequence, 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 devoting 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.

1.1 Engine combustion cycles

Heat carried away by the lubricating oil and heat lost by radiation amounts to 5 percent of the total heat supplied. Unless engine is adequately cooled, the engine seizure will result. 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 amount 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.

1.2 Objectives

Following are objectives for my research work:

1. To study the functioning of design and analysis of 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
5. To find out peak stress in the engine block for different combustion pressures. To find out peak surface temperature in the engine block when there is no cooling mediums such water and oil. To find out peak temperature in the engine block when cooling mechanisms are simulated.

2. Literature Review

M. Groeneweg, (2018). 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, (2018). 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, (2017). 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, (2017). 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.

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, (2018). 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 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, (2015). 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.

3. Finite Element Method

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.

The power of the finite element method resides principally in its versatility. The method can be applied to various physical problems. The structure can have arbitrary shape, loads, and support conditions. Mesh can mix elements of different types, shapes, and physical properties. This great versatility is contained within a single computer program. User input data controls the selected problem type, geometry, boundary conditions, element selection, and so on. Another attractive feature of finite elements is the close physical resemblance between the actual structure and finite element method. The finite element method also has disadvantages . A specific numerical result is found for a specific problem: A finite element analysis provides no closed form solution that permits analytical study of the effects of changing various parameters. A computer, a reliable program, and intelligent use are essential. Experience and good engineering judgments are needed in order to carry out real analysis.

Following are the need of FEA for problem solving.

1. To reduce the amount of prototype testing. Computer simulation allows multiple scenarios to be tested quickly and effectively.
2. To simulate designs that are not suitable for prototype testing. Example: Surgical implants, such as an artificial knee
3. The bottom line are cost savings, time saving reduce time to market and to create more reliable, better-quality designs

There are so many types of analysis that can be performed by finite element concepts in context to mechanical engineering. They are

1. Structural analysis
2. Thermal analysis
3. Computational fluid dynamics analysis
4. Coupled physics (coupling of thermal-structural, coupling of fluid –thermal)

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. The average temperature of the upper portion of the engine block (without cooling mechanism) was about 1400oC against the 750oC when it enjoys water and oil and, atmospheric cooling in a cast iron block. Peak stress was in the engine block for a gas pressure of 120 bars = 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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