

A review on Transient Thermal Analysis of CAD configured IC engine Piston to understand its Thermal Behavior

Mrs. Anjali Suresh Bal¹, Prof. S. R. Shekokar²

¹ PG Student ME, Department of Mechanical Engg CAD CAM, Padm. Dr.V. B. Kolte College of Engineering, Malkapur, Maharashtra, India

² Assistant Professor, Department of Mechanical Engg CAD CAM, Padm. Dr.V. B. Kolte College of Engineering, Malkapur, Maharashtra, India

DOI: 10.5281/zenodo.19333067

ABSTRACT

Modern IC engine pistons are highly precise and work under heavy thermal pressure. They are designed to withstand under thremostress circumstances. Metallurgy behind the piston manufacturing allows him to control his workability in engine running conditions. It is one of the engine components which always work under different stresses and forces while engine runs. Friction and higher working temperature always challenge piston to work smoothly without failing.

Most of the pistons are made up of aluminum alloys and has very smooth surface to reduce friction and they are oil cooled. As it works under higher temperature, it may affect the workability of piston and thermal stresses could cause the issues like crack propagation, wear and tear etc. It is observed that, piston experiences lots of forces which are transient or continuous in the nature as per the vehicle running requirements. Hence it is obvious to understand the behavior of piston during such loading conditions.

In this paper several articles available on Piston analysis are reviewed and their summery is presented here. The detailed review is done to draw a suitable conclusion which will help to precede further analysis study based on FEA package like ANSYS.

Keywords :- Transient Thermal Analysis, CAD Software, FEA package, CAD configuration

1. INTRODUCTION

An engine piston is a crucial, cylindrical component that moves up and down inside an engine cylinder, converting the force from fuel combustion into mechanical energy by pushing a connecting rod, which turns the crankshaft to power a vehicle. Made from aluminum or steel alloys, pistons create a gas-tight seal with piston rings, withstanding extreme heat and pressure to facilitate the four-stroke cycle (intake, compression, power, exhaust) that drives the engine's continuous operation, playing a vital role in engine efficiency and power.

Key Functions

Energy Conversion: Transforms the explosive energy from burning fuel into linear motion.

Force Transmission: Transfers this force via the connecting rod to the crankshaft, creating rotational motion.

Sealing: Piston rings create a tight seal against the cylinder wall, preventing gas leakage (blow-by) and oil contamination.

Heat Transfer: Conducts combustion heat away from the cylinder, protecting other components.

2. LITERATURE SURVEY

Till date research shows us that the design of frame structure is improved and brought to withstand heavy loading. But considering various conditions in which frames needs to be withstand a proper design method needs to be adopted which is varying now a days with different manufacturers.

Article [1] To further improve the thermal state of the piston for better thermal design, a multi-objective optimisation algorithm was used in this paper to find the best combination of design variables. The results show that thermal barrier coating (TBC) can effectively prevent heat transfer to the piston, and the thicker the ceramic layer, the better the thermal insulation effect. The maximum temperature and maximum thermal stress of the optimised piston matrix can be reduced by a maximum of 55.54 °C and 43.94 MPa, with a reduction of 15.08 % and 25.43 %, respectively, compared with that of the aluminium alloy piston of 368.39 °C and 172.76 MPa. Moreover, the thermal stress at the bottom of the combustion chamber, a larger cross-sectional area of the cooling gallery can dissipate more heat, which can have a more significant impact compared to the thickness of the ceramic layer. The large temperature gradient causes the maximum thermal stresses of the TBC piston to

occur on the surface where the metal bonding layer contacts the piston matrix. Such high thermal stress is the main cause of coating delamination. The findings of this study can provide a reference for improving the thermal state of the piston and enhancing the engine performance.

Article [2], The objective of this research work is to optimize the stress variations at the top of the piston in real engine conditions. During this pressure analysis on the examined surface of the piston, the thermal behavior is examined. The operating gas pressure, temperature and piston material functions are used as investigation functions. The analyzes carried out showed that the upper part of the piston could be damaged or broken due to the temperature caused by the working conditions, as the replacement of damaged or non-functioning parts is very expensive and usually difficult to obtain. Concave and convex piston profile designed in Solid Work 2023, used to design the piston geometry and for FEM analysis to optimize the thermal behavior of the used ANSYS R23.0 piston. Aluminum alloy and gray cast iron material for piston construction. Stress and displacement are analyzed for the piston by applying pressure to it in the structural analysis. By observing the results of the analysis, we can decide whether the piston we are designing is safe or not under the applied load conditions. Heat flow and thermal temperature distribution are analyzed using piston surface temperatures in thermal analysis.

Article [3], The purpose of this paper is to determine the maximum value of the boost pressure of an existing gasoline engine, without causing damage to its piston. To achieve this goal, the stress and strain state of the piston was determined using finite element analysis (FEA) with consideration of the influence of temperature at different values of the boost (intake) pressure. The temperature distribution of the piston was determined using transient thermal analysis. The analyses were performed using SolidWorks Simulation. The obtained results were compared and analyzed.

Article [4], The main goal of this research is to look into the analysis of a piston with a design change in order to reduce volume and improve efficiency. This necessitated conducting a thorough thermal analysis. The investigation is focused on dynamic, model, and transient thermal analysis. The focus of this research is on performing analysis and material optimization in the piston. The piston is designed in two stages in this work: design and analysis. First, use the modelling Pro/E software to create the piston model according to the design specifications. After loading the piston model into the engineering simulation and 3D design software ANSYS, the boundary conditions are applied to the piston. Then several characteristics (stress and deformation) are analyzed, and the findings are quickly obtained. The piston is optimized for the piston material in this study. The thermal analysis is carried out to determine the overall heat flow in the existing piston under the specified temperature parameters. The temperature acting on the piston's surface is applied. The findings were also utilized to calculate the total heat flux of a given material.

Article [5], The piston is thought to be a standout amongst the most essential parts in a reciprocating engine, reciprocating pumps, gas blowers and pneumatic barrels, among other comparable mechanisms. As most critical part, is that less time is required to outline the cylinder and simply a couple of essential details of the engine. Actually, due to high heat transfer through the piston, the outer shape of the piston crown will be deformed. So due to this problem here computational testing has been performed on ANSYS simulation software with three different materials and observed that stress of piston with ALSI AI alloy has maximum stress of 50.79M pa piston made of M-124 cast AL composite stress value is 50.54M pa. Furthermore, maximum stress on M-124 forged AL alloy is found to be 50.23M pa and here observe that in case of deformation, piston made of ALSI AI alloy found to have maximum deformation of 1.06mm and when piston made of M-124 cast AL combination then maximum deformation is 0.88mm. What's more, maximum deformation on M-124 forged AL alloy is found to be 0.086mm and here observe that in case of heat flux, piston made of ALSI AI alloy is found to have maximum heat transfer of

3.3w/mm² is observed. When piston made of M-124 cast AL combination then maximum heat transfer of 3.4w/mm² and maximum heat flux on M-124 forged AL alloy is found to be 3.6w/mm². So the aluminium alloy M-124 is the best manufactured composite material So this material is suggested for manufacturing work.

Article [6], This paper deals with the study of assembly of piston, connecting rod and crank shaft of a four wheeler petrol engine. The components of the assembly must be rigid and the assembly must move as a mechanism. Therefore, the analysis should include rigid-body analysis and flexible-body analysis. Therefore the forces exerted on the components when the engine is revving have to be calculated and these forces are used to calculate the dynamic stresses in the component of interest i.e. the connecting rod. It is proposed to change two new sets of materials for the components of the assembly and investigate the parameters by performing static, dynamic and thermal analyses, thermal analysis involves analyzing the thermal flow, temperature distribution by applying temperature on the surface of the piston. By looking at both analysis results, we can decide whether our designed piston is safe under the applied load conditions. Thus finally a comparative study is conducted by showing different results of analysis of pistons using different materials.

Article [7], Internal combustion engines produce exhaust gases at high temperature and pressures. As these hot gases passes through the exhaust valve ,temperatures of the valve ,valve seat, and the stem increase .To avoid

any damage to the exhaust valve assembly, heat is transferred from the exhaust valve from different parts, Especially the valve seat insert during the opening and closing cycle as they come into contact each other. In this article, A Finite- Element method is used for modeling the transient thermal analysis of an exhaust valve. The temperature distribution and resultant thermal stresses at each opening and closing time are obtained. Detailed analyses are performed to estimate the boundary conditions of an internal combustion engine. The modeling includes exhaust valve, seat, guide, and spring. The analysis continues until a steady state condition is obtained. In this study ANSYS is employed for modeling and analysis of the exhaust valve. A Methodology is developed for transient thermal analysis of the exhaust valve.

Article [8], The piston is the most important part of the engine, which is subjected to the thermal and mechanical stresses. The role of the piston is to guide the movement of the rod while transmitting the gases pressure forces, in order to make the volume variation inside the cylinder. Piston is a reciprocating part of engine which converts thermal energy into mechanical energy. There is thermo-mechanical load on the piston, there is fatigue failure due to cyclic thermal and mechanical loading. To increase the life of the piston, there has been more research going on in modifying the design of the piston, changing the material and also changing the method of the manufacturing. This uses standard procedure of obtaining critical dimensional values from empirical formulae and material constants resulted from previous experimental data. A three Dimensional model can be made using solid modelling software's like CATIA and SOLIDWORKS and mesh can be generated. Further, a finite element model can be made and analysis can be carried out using software's like ANSYS. thermal flux and thermal temperature distribution is analysed by applying temperatures on the piston surface in thermal analysis

Article [9], Knowledge of piston and cylinder wall temperature is necessary to estimate the thermal stresses at different points; this gives an idea to the designer to take care of weaker cross section area. Along with that, this temperature also allows the calculation of heat losses through piston and cylinder wall. The proposed methodology has been successfully applied to a water-cooled four-stroke direct-injection diesel engine and it allows the estimation of the piston and cylinder wall temperature. The methodology described here combines numerical simulations based on FEM models and experimental procedures based on the use of thermocouples. Purposes of this investigation are to measure the distortion in the piston, temperature, and radial thermal stresses after thermal loading. To check the validity of the heat transfer model, measure the temperature through direct measurement using thermocouple wire at several points on the piston and cylinder wall. In order to prevent thermocouple wire entanglement, a suitable pathway was designed. Appropriate averaged thermal boundary conditions such as heat transfer coefficients were set on different surfaces for FE model. The study includes the effects of the thermal conductivity of the material of piston, piston rings, and combustion chamber wall. Results show variation of temperature, stresses, and deformation at various points on the piston.

Article [10], This study presents a comprehensive Finite Element Method (FEM) analysis conducted using Fusion 360 software to evaluate the static and thermal characteristics of pistons fabricated from alumina and Aluminum 6061. The research aims to compare and contrast the performance of these two materials under typical engine operating conditions. The static analysis investigates stress distribution, deformation, and overall structural integrity of the pistons when subjected to mechanical forces and pressures experienced during engine operation. Simultaneously, the thermal analysis assesses temperature distribution and thermal stresses, providing insights into the pistons' ability to withstand high temperatures. Detailed simulations were performed with realistic boundary conditions and material properties, allowing for a direct comparison of the performance of alumina, known for its high hardness and thermal stability, against Aluminum 6061, recognized for its lightweight and good thermal conductivity. The findings reveal distinct differences in stress handling, thermal management, and potential failure points between the two materials. This study offers critical insights into material selection and design optimization for enhancing piston performance and durability in modern engines.

3. RESEARCH GAP

As I reviewed various studies available from recent to old publications it is observed that the Thermal analysis of piston is done by various authors and their results are published. It is also observed that the most of the studies are focusing on the steady state thermal analysis. Whereas in running condition the transient state thermal analysis is more suitable which is exactly simulating the actual working conditions of a piston.

Deeper dive into the recent studies available on the thermal analysis of a piston will uncover the fact which demands more advanced thermal analysis based on non linear circumstances. It is only because the piston is working under non linear conditions. Transient state thermal analysis with layer by layer meshing can predict exact behavior of piston under loading. While searching on recent studies available on "Transient state thermal analysis", it is found that no considerable studies are available in this regard which actually create gap in research.

4. CONCLUSIONS

To fulfill this gap, I have planned to perform this experimentation virtually in order to achieve my desired goal of understanding behavior of piston under loading condition. Also reference papers attached can prove the gap which must be filled.

5. REFERENCES

- [1] Yang Liu a,b , Jilin Lei a,b,* , Xiwen Deng a,b , Yi Liu a,b , Dongjun Sun c , Yuankan Zhang c, “Research and analysis of a thermal optimisation design method for aluminium alloy pistons in diesel engines”. Contents lists available at ScienceDirect Case Studies in Thermal Engineering, Available online 24 October 2023 2214-157X/© 2023 The Authors. Published by Elsevier Ltd.
- [2] D.Hari krishna1 , CH.Veeru Naidu2 , A.Narendhra Kumar3, “Thermal Analysis of Different Piston Head Profiles by Using FEM”. International Journal for Multidisciplinary Research (IJFMR) E-ISSN: 2582-2160 • Website: www.ijfmr.com • Email: editor@ijfmr.com, IJFMR230611430 Volume 5, Issue 6, November-December 2023
- [3] Ambarev, K.; Taneva, S. “Thermal and Structural Analysis of Gasoline Engine Piston at Different Boost Pressures”. Eng. Proc. 2025, 100, 38. <https://doi.org/10.3390/engproc202510003>
- [4] Mr. Ratnakar Lande, 2Prof. Prashant Awachat, 3Prof. Tejpal Parshiwani, “ANALYSIS AND OPTIMIZATION OF PISTON OF IC ENGINE”. www.ijcrt.org © 2021 IJCRT | Volume 9, Issue 7 July 2021 | ISSN: 2320-2882, IJCRT2107343 International Journal of Creative Research Thoughts (IJCRT) www.ijcrt.org d92
- [5] Neha Choubeya,* , Ashish Kumar Shrivastava , Abhishek Choubey , Swapnil Singh , Balendra Bhaskar, “Thermal analysis on two wheeler piston with different materials by using FEA method”. Int. J. Nonlinear Anal. Appl. 13 (Special issue for ICDACT-2021), 147–155 ISSN: 2008-6822 (electronic) <http://dx.doi.org/10.22075/ijnaa.2022.6340>
- [6] Ravi Ranjan1 , Prof. D. S. Rawat2 and Dr. Sumit Rai2, “Thermal Analysis of Piston, Connecting Rod and Crank Shaft Assembly using Catia and Ansys Software; A Review”. International Journal of Research Publication and Reviews, Vol 5, no 1, pp 594-598 January 2024.
- [7] Mr. N. Raghuveer1 , Puli Hari Shankar2 , Kadiyala Rupananda Ganesh Kumar3 , Ramavath Arun Kumar Naik4
- [8] , Sai Durga Nishith Mediseti5, “Design and Simulation of Steady State Thermal Analysis of Exhaust Engine Valve”. International Journal of Scientific Research & Engineering Trends Volume 11, Issue 2, Mar-Apr-2025,
- [9] ISSN (Online): 2395-566X
- [10] Vijay Pokharkar1, Saurbh Palkhe2, Aditya Pawar3, Aaditya Yadav4, “Thermal Analysis of Piston”. International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056 Volume: 08 Issue: 05 | May 2021 www.irjet.net p-ISSN: 2395-0072
- [11] Subodh Kumar Sharma,1 P. K. Saini,2 and N. K. Samra3, “Experimental Thermal Analysis of Diesel Engine Piston and Cylinder Wall”. Hindawi Publishing Corporation Journal of Engineering Volume 2015, Article ID 178652, 10 pages <http://dx.doi.org/10.1155/2015/178652>
- [12] □Chandra Mohana Reddy G1 , Safeeruddin Khan2 , Abdul Saddique Shaik3 , and Murali Krishna CH1, “Performing FEM Analysis to Evaluate the Static and Thermal Characteristics of a Piston”. MATEC Web of Conferences 405, 03007 (2024) ICASMMT 2024 <https://doi.org/10.1051/mateconf/202440503007>