ISSN: 0974-5823 Vol. 7 No. 2 February, 2022

International Journal of Mechanical Engineering

NUMERICAL ANALYSIS OF DIESEL ENGINE COMPONENT UNDER THERMAL LOADING

A.B.K RAJAN [1], DR.SELVAKUMARAN THUNAIPRAGASAM [2] , JAYA CHRISTIYAN K.G [3],
VINODH S [4], SIVAGANGAI T [5]

[1]Associate Professor, Department of Mechanical Engineering, Jawahar Engineering College, Chennai, Tamil Nadu, India

[2] Associate Professor, Department of Aerospace Engineering, SRM Institute of Science and Technology, Chennai, Tamil Nadu, India

[3] Mechanical Engineering, M.S Ramiah Institute of Technology, Bangalore, India

[4] Department of Aeronautical Engineering, Mahendra Engineering College, Namakkal, Tamil Nadu, India

[5] Assistant Professor, Hindustan Institute of Technology And Science, Tamil Nadu, India

Abstract –

The goal of this study is to statistically examine the thermal stress on the piston crown of a marine diesel engine. It examines the piston crown's basic stress structure and distribution. Because it is subjected to pressure variations and heat stress during normal engine operation, the piston crown is one of the most problematic components of an internal combustion engine. Wear, heat, and fatigue-related damage mechanisms all have various causes. Thermal and mechanical stress have a significant impact on fatigue damage, whether at room temperature or at high temperatures. The basic stress contour and distribution on the piston crown were explored using an analytical model and Solid Works to model and simulate the piston crown. Aluminum alloy and malleable cast iron were used to make the piston model. When a pressure of 5MPa is applied, the result of Malleable Cast Iron outperforms the result of Aluminium Alloy.

Key Words: Marine Engine, Thermal stress, loading, Piston

I. Introduction

Thermal stresses on marine engine components within the combustion chamber of marine diesel engines are the fundamental limitations limiting the performance and sturdiness of marine engines. The piston head/crown is one of the most severely loaded elements, since it generates various sorts of material losses and excessive expansion in the piston's diameter, resulting in galling, when heated above the piston's permitted set temperature. Temperature variations can contribute to the formation of crakes, which can lead to leaks and make the engine unable to function correctly [1]. As a result, the combustion chamber is on the loser's side.

During engine operation, heat causes reversible and irreversible dimensional changes in the piston, affecting the valve of the piston-cylinder assembly clearance, the clearance of the tightness of the combustion chamber clearance, and thus the side of the change losses. Because the loss of charge during compression impacts the essential excess air ratio within the combustion chamber, this is especially true for marine engines. A piston cylinder assembly that is wrongly classified has a detrimental influence on oil consumption, the engine's ability to start, and thus loudness. The proper placement of engine rings has a significant influence on piston temperature.

The piston must transfer 60 to 80% of the heat it collects from the working medium into the cylinder through the rings. The objects required for the rings have incompatible requirements. As a result, the rings must be placed as far away from the piston head as possible to avoid thermal stress [1]. They may need to be put higher to reduce the thermal burden on the piston.For all engine speeds and loads, reducing the distance between the ring and therefore the piston head results in a particular drop in piston temperature at each of its points.

Changing the number and heights of rings causes a change in the piston temperature due to differences in the surface where heat exchange occurs. Aside from the design conditions of marine engines, the operating conditions of the engine include a change in the effective pressure. Assuming that mechanical efficiency remains constant, an increase in the typical effective pressure is equivalent to better heat emission, resulting in a rise in piston temperature.

Because a piston has two types of stress, modelling thermal stresses can be difficult.

- Thermal stress is caused by the vertical distribution of a homogenous and regular temperature gradient at the best and lower temperature at the worst. There is an uniform and regular temperature gradient along the height of the component in the radial direction. Thermal deformations below the operational bowl rim temperature have been observed to be confined by the surrounding material in the bowl rim area where temperatures are higher. The creep effect creates tensile residual stress on the bowl rim as the piston cools down following creep relaxation of the high compression stresses. As a result of this cycle, cracks emerge all over the rim area.

- A change in temperature at the top of the piston as a result of recent gas flow or fuel impingement causes thermal stress (related to high-pressure infections). As a result of this distribution, warmer zones are localised [2].

In an engine, temperature differences allow heat to be transferred from a higher to a lower temperature. During the intake stroke, heat is transferred to the gases; however, during the combustion and expansion processes, heat is transferred from the gases to the walls, affecting the piston head/crown, as well as a few other components such as the seal, and causing deformations in the piston skirt, valves, and plate [3].

The piston is the most significant component of the engine and one of the most complicated of all the combustion engine components. There are a plethora of research papers suggesting new shapes, materials, and production procedures for engine pistons, and this evolution has been ongoing for decades and deserves close scrutiny. Despite these efforts, a considerable number of Pistons have been destroyed.

The most prevalent sources of damage processes are wear, temperature, and fatigue. Damaged pistons are generated by stress generation, which includes thermal and mechanical stress, in addition to wear and fatigue. The piston is only vulnerable to pressure, but temperature is also important; heat damages the piston severely, and overheating causes severe damage. A thermal stress research was also carried out, with the findings revealing that the strain generated is quite similar to the strain obtained when only considering pressure in the analysis.

As a result, the temperature difference (T) between the piston head's centre and sting was taken into account. The resultant stress was achieved as a result of the effective combination of temperature and pressure, with the valve's permitted stress of 124.4 MPa, which is significantly closer to the allowable stress when only pressure was taken into account. They worked on the piston even further to make it stronger and less prone to deformation, which demanded structural changes to lower the piston's temperature.

For biofuel, a zirconium-coated piston that is lighter and stronger is used. For the highest load, the coated piston was put through a Von Mises test with ANSYS. To locate the strain owing to pressure and heat changes, the strain distribution on various parts of the coated Pistons was examined. Because the design and weight of the piston influences engine performance, Von Misses Stress is increased by 16 percent, and a stronger, lighter piston is optimised at a cheap cost and in less time.

To understand the strain due to pressure and heat variation, ANSYS was used to analyse the strain distribution within the various components of the piston [4]. The internal-combustion engine piston was subjected to a three-dimensional definite-element analysis for design improvement, taking into account the reference's thermal boundary conditions. The findings revealed that piston temperature is the most likely cause of piston safety, piston deformation, and hence high stress, and that structure improvement can further lower piston temperature.

The temperature field, thermal, mechanical, and paired thermal-mechanical stress of a 2-stroke 6S35ME marine diesel piston are modelled [3]. Bhagat and coworkers (2013). In engine piston design, failure analysis, and optimization, the distribution and magnitudes of the aforementioned strength measures are useful. The piston model was created in Solidworks and then imported into ANSYS for processing, loading, and post-processing. The material model was chosen as the 10-node tetrahedral thermal solid 87. Simulation parameters included piston material, combustion pressure, inertial effects, and temperature.

The strain distribution of the piston is described using the finite element approach in this research (FEM). FEM is carried out using computer-aided engineering (CAE) software. The major purpose of the study was to investigate and assess the strain distribution of pistons throughout the combustion process under various engine settings. The article describes how to use the FEM approach to optimise the mesh in order to predict the component's top stress and important regions. The impact of crown thickness, barrel, and piston top land height on stress distribution and overall deformation is measured during the analysis of an actual four stroke engine piston. Statistical analysis is used throughout the optimization process. ANSYS is used to do FEA analysis for optimal geometry.

The strain distribution and thermal stress of three different alloy pistons are described using the finite element method (FEM). The simulations used operating pressure, temperature, and piston material properties as parameters. Specifications from a four-stroke single-cylinder engine were used to study the pistons in question [3].

In an experimental investigation, Uzun and Akcil looked at the impact of ceramic coatings on the performance of a diesel engine and exhaust emissions. Ceramic coatings can help to minimise CO and particle emissions while also removing visible smoke and increasing combustion efficiency. The performance of the diesel ceramic coating was evaluated using a hydraulic engine dynamometer. The coatings were put to the test to see how effectively they could control particle emissions, smoke emissions in exhaust gases, horsepower, speed, and fuel rate. The concentrations of CO and hydrocarbons were lower than expected [5].

A commercial code, ANSYS, was used to conduct thermal assessments on pistons coated with MgO-ZrO2 material. Buyukkaya and Cerit used a commercial code, ANSYS, to conduct thermal studies on a typical (uncoated) diesel piston made of aluminium silicon alloy and steel, as well as thermal analyses on pistons coated with MgO-ZrO2 material. The results of four different pistons were compared. The impact of coatings on the thermal behaviour of pistons were investigated. The maximum surface temperature of the coated piston with poor thermal conductivity material was increased by around 48% for AlSi alloy and 35% for steel [6].

On piston four-stroke engines, FEA was also used to explain the seizure's strain distribution. Computer-aided design (CAD) software was used to do the finite element analysis. The most essential aims were to investigate and analyse the thermal stress distribution of pistons during the combustion process. This study shows how to optimise the mesh and forecast the component's top stress and key regions using a finite element analysis technique.

The optimization is used to lower the strain concentration at the piston's upper end (head/crown, piston skirt, and sleeve). Computer-aided design (CAD) and Pro/ENGINEER software will be used to create a structural model of a piston. Furthermore, the ANSYS programme was used to do the finite element analysis.Rakopoulos and Mavropoulos computed the temperature field and warmth flow field using a piston model under stable and transient engine operation conditions.

Three-dimensional finite-element analyses were utilised to describe difficult geometry metal components, and an acceptable level of agreement between theoretical predictions and experimental measurements was obtained [7]. Muhammet used a partially ceramic covered SI engine piston to measure the temperature and, as a result, the stress distributions. With comparisons to uncoated piston data, the effects of coating thickness and width on temperature and stress distributions were investigated. It was revealed that the temperature of the coating surface increased when the thickness of the coating was raised at a slower rate. With a 0.4 mm coating layer, the piston's surface temperature was boosted to 82 °C.

The traditional stress on the coated surface decreases as the coating thickness decreases, reaching a minimum of about 1 mm at which point the stress value was the lowest. However, as the coating thickness exceeds 1 mm, it rises. When it comes to the bond coat surface, the typical stress decreases as the coating thickness increases, while the maximum shear stress increases at a slower rate. The best coating thickness was found to be around 1 mm under the aforementioned conditions [8]. Li used a three-dimensional finite element model of an aluminium diesel piston to calculate operating temperatures. He showed that the shape of the skirt was crucial in reducing scuffing and friction [9].

Prasad and Samaria used thermally insulating material on the piston crown face, especially partially stabilised zirconia (PSZ), and found that heat loss through the piston was reduced by 19% [10]. Low cycle fatigue resulting from localised yielding when the coating is heated and in compression is postulated as the first cause for coating failure [11]. Pierz looked into the development of heat barrier coatings for diesel aluminium pistons and discovered that the results accurately anticipated piston temperatures and stresses, as well as material strength data.

Despite the fact that many research studies propose new engine piston generation, materials, and manufacturing techniques, there are a large number of damaged pistons in these studies, and none of them considered a comparative based analysis of fabric characteristics to thermal effect and performance deterioration. The goal of this study is to create an integrated analytical and numerical framework for calculating thermal loading effects and, as a result, the point of failure of various materials.

II. METHODOLOGY

2.1 Data of the engine specification

The results of the numerical study are based on the characteristics of a marine diesel engine under varying heat loads during the course of a journey. The experimental engine's specs are listed in Table 1.

Table 1. Engine technical specifications

Description	**Value**
Max pressure ‘pmax’	5 MPa
Temperature in combustion chamber ‘T’	900 K
Configuration	Two-stroke diesel engine cooled by air
Bore ‘D’	300 mm
Power ‘Ne’	300 kW per one cylinder
Piston cooling	By oil maximum temperature500K

2.2 Thickness crown calculation

The stresses applied to the piston were first computed using the piston crown thickness. It's worth noting that the thickness of the line reveals how the piston's stresses work. One approach is to calculate the thickness without taking into account the possibility of adding ribs later.

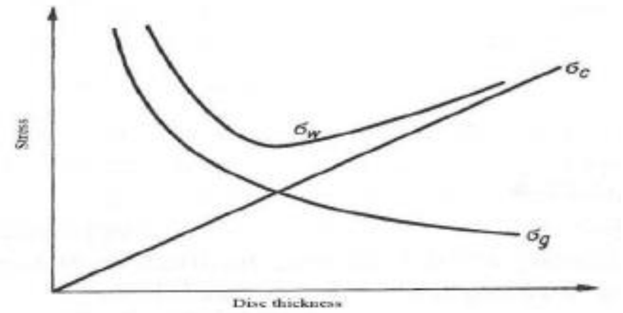

Figure 1. Dependence of the Stresses in Function of the Disc Thickness

The crown is put under the least amount of stress at a certain thickness. The purpose of the initial calculation is to arrive at an approximate estimate. To begin, you'll need a support diameter. $\mathcal{D}_p$(0.80÷86) D= 258mm should be the dimensions. 0.86 is utilised as a worst-case scenario.

The piston crown is under the following pressure:

$\mathcal{P}=(\pi \mathcal{D}_p/8)\ P_{max}$ --------------(1)

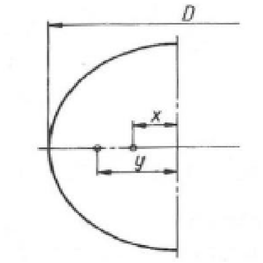

Figure 2. Application of the maximum pressure ‘X’ and reaction applied in ‘Y’

$X=(2/8)\ (\mathcal{D}_p/\pi)$ --------------(2)

$y=(\mathcal{D}_p/\pi)$ --------------(3)

Bending moment value combining (1), (2) and (3):

$M=P(Y-X)= (\mathcal{D}_p S, P\ max/24)$ --------------(4)

The minimum thickness of the crown:

$g=\mathcal{D}_p/2\ \sqrt{}Pmax/Kg)$ --------------(5)

2.4 Numerical Software Demonstration

In this study, SOLIDWORKS 2016 CAD was used to create and simulate the piston in order to check for deformation and make any model updates that were needed. SolidWorks is a computer-aided design (CAD) and computer-aided engineering (CAE) tool for modelling, designing, assessing, and simulating mechanical equipment. It is based on Microsoft Windows.

3. RESULTS AND DISCUSSION

According to the findings, there is an optimal thickness at which the crown is under the least amount of stress. To calculate the needed diameter, this was built using the analytical solution. Table 2 illustrates the outcome of the analytical solution, which explains the critical value that characterises the piston crown's thermal loading characteristic.

Table 2. The component's analytical analysis yielded the following result:

Material characteristics experimented	Results
Centroid centre horizontal X	54.75mm
Centroid centre vertical Y	82.12mm
Bending moment effect (M)	0.0036Nm
Minimum piston crown thickness (g)	32.25mm
Maximum allowable bending stress of Aluminum (Kg)	80MPa

The research shows that component thickness differs when it comes to pressure and thermal stress analysis. Effective cooling techniques have also been discovered to play a key role in decreasing component thermal stress, especially in variable loading conditions. The results also show that the maximum allowable stress in a malleable cast iron cast was not exceeded. In the calculation, the usual force forcing the piston against the cylinder liner is also taken into account. The greatest value is reached when the crank is deflected 35oC outward from the cylinder axis. The pin's deflection caused a bending stress of 182 MPa, while the pin's localization caused a bending stress of 125.5 MPa.

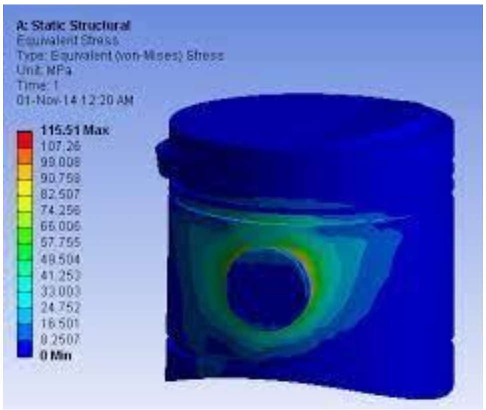

Figure 3. Pressure of 5MPa being applied to the Piston Crown

4. CONCLUTIONS

For two materials considerations, the stress distribution operating on the Piston Crown was investigated using both an analytical and a Solid-Works approach (Aluminum Alloy and Malleable Cast Iron). The findings of the analysis revealed which Solidworks material properties may be subjected to loading scenario testing. According to the stress distribution data from the simulation, cast iron is a superior material for the piston than aluminium alloy. According to study, malleable cast iron can withstand a higher temperature gradient than aluminium alloy.

Malleable Cast Iron may also sustain a higher temperature gradient than Aluminium Alloy, according to research. Each metal has a yield strength, and temperature induced failure (fracture, cracks) happens when the greatest stress exceeds the yield strength. The test was carried out with a variety of materials and a piston pressure of 5Mpa. The piston manufactured of Aluminum Alloy will fail under the same loading conditions, however the piston made of Malleable Cast Iron will not fail.

The findings clearly show the loading characteristics of various materials, as well as the loading point that has the biggest impact on their performance and failure.

It is clear that the Aluminum alloy is particularly vulnerable to thermal loading at the critical value of 5MPa. This lays the technical and monitoring groundwork for the plant's operation in critical loading situations for marine vessels in inclement weather.

REFERENCE

1) Gustof, P. and Hornik, A. (2016). Analysis of thermal stress of the piston during non-stationary heat flow in a turbocharged Diesel engine. Journal of IOP Science.
2) Dilip, K., Sonar, and Madhura C. (2015). Theoritical Analysis of Stress and Design of Piston Head using CATIA & ANSYS. International Journal of Engineering Science Invention, (6) 4.
3) Bhagat, A. R. and Jibhakate, Y. M. (2013). Thermal analysis and Option of I. C. Engine Piston using Finite Element Method. Internal Journal of Mordern Engineering Research (IJEM), (4), 2.
4) Rajam, V. P. and Muthy, V. K. (2013). Linear Static Structural Analysis of Optimised Piston for Bio-Fuel using ANSYS. Journal of Mechanical and Prodution Engineering research and development (IJMPERD), (2), 3.
5) Uzum, A. (1999). Effects of Thermal Barrier Coating on a Turbocharged Diesel Engine Performance. Journal of Surface and Coating Technology.
6) Buyukkaya, E. and Cerit, M. (2012). Thermal Analysis of a Ceramic Coating Diesel Engine Piston using Finite Element Method. Internal Journal of Mordern Engineering Research (IJMER), (4), 2.
7) Rakopoulos, C. D. and Mavropoulos, G. C. (1996). Study of a Steady and Transidient Temperature field and Heat flow in the Combustion Chamber Components of a medium Speed Diesel Engine Using finite element asnalysis. Internal Jounal of Energy Research.
8) Li, C. H. (1986). Thermoelastic Behaviour of an Aluminium Diesel Engine Piston. General Motors Research labs. Warren SAE paper.
9) Muhammet, C. (2011). Thermo Mechanical Analysis of a Partially Ceramic Coated Piston used in an SI Engine. Surface & Coating technology.
10) Prasad, R. and Samaria, N. K. (1990). Comput Struct.
11) Pierz, P. M. (1993). Thermal Barrier Coating Development for Diesel Engine Aluminium Pistons.