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A Review of Thermal Analysis and performance of I.C. Engine Piston using CATIA and ANSYS software

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ABSTRACT

The piston is a component of IC reciprocating engine. It is the moving component that is contained in a cylinder and is closed by piston rings. In an engine, it is intended to transmit the force of the expanding gas in the cylinder to the crankshaft via a piston rod and/or a connecting rod. This working condition can cause piston stress damage such as piston side wear and piston head/crown cracks etc. Investigations indicate that the greatest pressure appears at the upper end of the piston and that stress concentration is one of the main causes of fatigue failure. The temperature field distribution and structural analysis of equivalent stress and total deformation values were plotted against the cylinder pressure values. This analysis predicts which part of the piston structure may be damaged at the top or bottom of the skirt. Finally, the thermal-mechanical stresses developed in the piston with less deformation were improved by finite element analysis (FEM).

Keywords- Stress analysis; equivalent stress; Piston.

1 Introduction

The piston overheating can only occur when something burns or scratches the oil film between the piston and the cylinder wall. Understanding this, it is not difficult to see why the high strength oils for diaphragms are so cravings. High-quality oils can provide a film that withstands the extreme heat and pressure loads of a modern high-powered engine. Thermal analysis is a branch of materials science in which the properties of materials are studied as they change with the change of temperature. The FEM method is commonly used for thermal analysis.

Due to the complex working environment of the piston; On the one hand, the piston FEA is becoming more and more difficult, on the other hand, although there are many proposed methods for applying the ideal design, it is not easy to determine the ideal parameters. In this study, a piston is used in a low-speed gas engine and a rated speed. To improve engine dynamics and economy, it is necessary that the piston carry out the optimization.

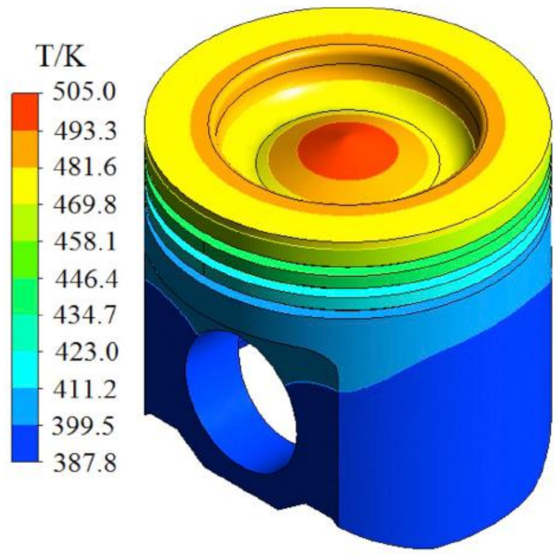

Figure 1 Temperature field distribution

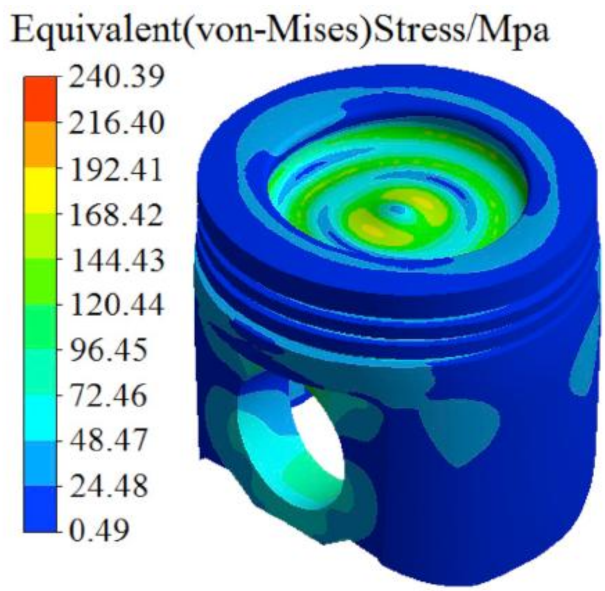

Figure 2 Von-Mises stress.

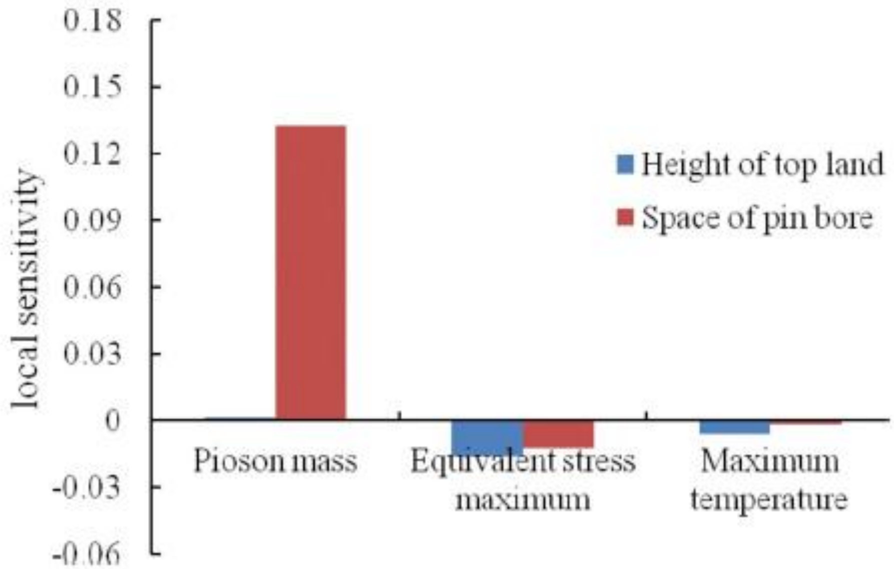

Figure 3 the piston sensitivity analysis.

2. Literature review

Several research articles have been published on this research work. Among them, specific articles were reviewed to establish the basis for this work for the comparative study of piston materials, namely aluminum 4032, carbon graphite and tungsten. It became necessary to calculate the piston temperature distribution to control thermal stress and deformations within acceptable levels. The temperature distribution allows the designer to optimize the thermal aspects of the piston design at a lower cost [1]. Serenad et al. [2] It was concluded that zamak has low deformation and high heat flux properties compared to other materials such as cast iron and aluminium. According to their results, the piston with Zamak has a higher heat flow value than conventional materials. The ZrB2 composite piston reinforced with SiC has lower deflection than aluminum alloy and gray cast iron for the applied temperatures and pressures. It is also noted that the pressure for all materials falls within the permissible limits for the respective substance [3].

Silicon and aluminum carbide have lower deformation, lower stress, and good temperature distribution compared to aluminum [4]. The engine operates at increased load and speed due to fuel combustion at high pressure and high temperature inside the engine cylinder. It produces high thermal and synthetic pressures on the piston inside the engine cylinder and if these pressures exceed the designed values, piston failure occurs [5].

Krishna Dutta Pandey et al. [6] compare structural steel and graphite for piston materials using FEA. Their analysis shows that graphite is better for piston materials because it has better thermal behavior and lower weight. The results showed that the maximum heat is transmitted in the piston made of carbon graphite.

Carbon graphite is lighter than 2618 aluminum alloy, and it also has a low coefficient of thermal expansion [7]. Kumar et al. [8] Static structural analysis, steady-state temperature analysis, and transient temperature analysis of the Al-4032 aluminum alloy piston were performed using ANSYS. It has been verified that induced voltages are the main factor in piston failure. Changes in temperature and heat flow with time are determined in a transient analysis. The maximum displacement is observed in the upper part of the aluminum alloy and gray cast iron piston. The highest maximum temperature value present in the piston is due to the thermal conductivity of the materials and the maximum total heat flux is absorbed into each of the piston materials. Thus, more research can be done using advanced materials [9]. The total heat flow varies with different types of materials. The total heat flow for structural steel and gray cast iron is calculated for the same network properties with similar geometry. The heat flow result shows that the variance in heat flow is not much greater by simulation or analysis. It also shows that the simulated heat flow values are much closer to the theoretical values calculated by the formula [10].

The review shows that simulations with FEA produce results similar to analytical ones. Thus, FEA has been adopted in this work for static structural analysis and steady-state thermal analysis. Structural analysis is necessary to find the effect of mechanical loads on piston materials.

3. Advantages of the piston

- Mechanical simplicity.
- Flexibility and reliability.
- Power to weight ratio.
- Multi-fuel capability.
- Low turbine operating temperature.
- Less vibration and noise.
- Less maintenance.
- Easy to start the piston.
- Highly suitable for waste heat recovery.
- Give a high degree of manoeuvrability.
- Less manufacturing cost.
- Low NOx emissions.
- It offers the HCCI combustion process.
- Internally balanced.
- Modularity.

4. Piston rings

In general, a compression ring and an oil ring as a piston ring assembly are connected to a replacement piston. The pressure ring works to prevent a phenomenon called bloating. High pressure flue gas flows into the crankcase in the combustion chamber. On the other hand, the oil ring has the function of suppressing excess lubricant on the inner wall of the cylinder liner. The main function of the piston rings is to close the combustion chamber from the rest of the engine. There are some considerations to consider before designing piston rings. The first piston ring should not be too far from the piston head. This increases the volume of space between the piston and the cylinder walls, which increases the secretion of hydrocarbon compounds into the exhaust gases. At medium speeds, the first touch takes on more than 75% of the total pressure. The choice of the number of rings should be the result of careful analysis, on the one hand, it depends on whether the gas passing through the crankcase should be minimal, and on the other hand, the number of rings determines the mass of the piston, the loss from height and friction. from the engine.

5. Materials

The adverse working conditions make the requirements for the materials used in the press very wide and varied. The materials used in the manufacture of the piston can be divided into the following groups:

1. Cast iron (non-alloyed steels and alloys)
2. Aluminum alloys
3. Special steel

The cast iron used for the plunger is usually a pearl body with separate blades. When gluing, a finer granular structure is obtained and it will improve the mechanical properties of the material. The advantages of cast iron are: good sliding properties, high wear resistance, slight decrease in strength and hardness at high temperatures, small coefficient of thermal expansion. The disadvantages are: high density and small thermal conductivity coefficient. The hardness of cast iron should be in the range of 180-240 HB and should also be adapted to the hardness of the rings and cylinder walls.

Also, for regular pistons at high speeds, light aluminum alloys are used. The advantages of aluminum alloys: low density (about three times less than cast iron), good thermal conductivity, easy casting and good workability. The disadvantages are: the average coefficient of linear expansion (2.5 times greater than that of cast iron), lower hardness, lower strength at elevated temperatures, and finally a slightly higher price. The small density of aluminum allows building lightweight pistons, which positively affects fuel consumption and also reduces the stress and pressure of inertial forces.

6. Piston pin

The piston pin is used to transfer pressure from the piston to the connecting rod, and is also responsible for providing an oscillating movement of the connecting rod. Harsh working conditions, high temperatures, tight spaces and small sizes make calculations very difficult.

6.1 Piston pin materials

Working conditions determine the properties of the applied materials. Great stress requires a very hard and wear-resistant surface and due to the oscillatory movement resistance to stress. These requirements lead to the use of low carbon steel C = 0.12 - 0.18%. After fabrication, the rivets are externally hardened to give them hardness and a wear-resistant surface.

6.2 Piston crown surface

One of the most important parts of the piston is the surface of the piston crown. Where combustion occurs and where maximum pressure is maintained by the flue gases. As far as pressure is concerned, no simplification is done, it's a steady state analysis, so in the worst case, maximum pressure is taken. y value = 3 MPa. When it comes to heat exchange between the gases and the surface of the piston crown, everything becomes much more difficult. The first approach taken was to stabilize the surface of the piston head, and this was later found to lead to incorrect results.

7. Piston redesign improvements

1. Reduction of piston crown thickness.
2. Improve piston ring temperature for more accurate results.
3. Increased cube height to reduce stress.
4. Introduction of barrel shape on top of piston.
5. Increase scrap ring height to fit reality.

8. Cooling system

Piston engines, especially internal combustion engines, are usually cooled with lubricating oil. Traditionally, this is achieved by spraying lubricating oil onto the piston to facilitate cooling to the underside of the piston head surface. In large engines this system becomes inefficient due to the huge amount of heat being transferred. To correct this problem, a large amount of oil spray is needed. This requires additional components such as oil storage tanks that are too large, which lowers the engine's power-to-weight ratio and increases engine manufacturing operating costs. Thus, the heat transfer between the piston and the lubricating oil is not uniform throughout the engine. This causes thermal gradients and stresses within the motor, which can lead to cracking.

9. Conclusions

The temperature distribution of the entire piston is very uneven, the highest temperature appears in the center of the upper part of the combustion chamber, the highest temperature value is 232 ° C and decreases from top to bottom along the piston axis. Piston, the lowest temperature appears at the bottom of the piston skirt, the minimum temperature is 114 ° C. The maximum temperature of the first groove in the piston ring is 190 ° C. If the temperature is too high here, the piston ring will malfunction and the cylinder will be damaged. In this study, oil spraying and oil cooling measures at the bottom of the piston were used to improve the temperature field and reduce the temperature. The crystallization temperature of the piston high temperature lubricating oil is 250°C.

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