IC engine design and analysis on ANSYS

[1]M PRAVEEN KUMAR ,[2]BANTU SAILESH
[3]SK HUSSIAN BASHA
[3]POLAMURI RAMA MOHAN REDDY
Department of Mechanical Engineering,
Nagole Univerisity Engineering and Technology Hyderabad

ABSTRACT

The upper surface of the piston is being monitored with a wok for stresses and temperatures. Pistons in IC engines are very sophisticated and essential to a vehicle's flawless functioning. The most prevalent reasons of piston failure are mechanical and thermal stress. The uneven distribution of temperature and the pressure on the piston head are taken into consideration in the piston analysis. The top surface of the piston might be damaged or cracked as a result of operating temperature since damaged or broken components are so expensive to replace and frequently difficult to remove. An ANSYS TOOL was used to construct this model. Hyper Mesh is used to mesh and clean up the CAD model. The FEA uses RADIOSS. You may use Hyper Works module OptiStructure to assist organise the model.

I.C. Engine and Ansys software are also in the list of terms, along with stress concentrations and FEA.

INTRODUCTION

Temperature and pressure increase when the fuel's energy is released, which causes engines to expand. Pressure and temperature increase rapidly in a short period of time. Part of this energy is converted to mechanical work via a piston in the combustion chamber. Construction begins with a cylinder with the piston crown, pin boss, and skirt all attached. An engine's compression forces are delivered to the crankshaft through the piston pin, connecting rod, and the piston pin boss. There are four basic roles for the piston: power transfer from working gas, sealing and directing the connecting rod linearly, and dissipating heat from combustion.. [1] Pistons must be able to adapt to changing operating conditions, be smooth while running, have little bulk, and have the lowest pollutant emissions and friction losses in order to function properly.. In compliance with conventional machine design and data instructions, this piston was constructed. It was created using ANSYS 16.2's Geometric module, which was utilised to generate the solid model of the piston. The Response Surface Optimization tool was used to fine-tune the piston after it underwent thermal mechanical evaluation (containing both static structural analysis and thermal analysis). This piston is compatible with TVS sooty Pep+ four-stroke SI engines.

The Piston Design Modeling

According to the design manuals and data sheets of each machines, pistons are made using a specified technique and specification. Size is measured using

the SI system of units. Piston head pressure, temperature, heat flow, stress and strain, length, diameter, and thickness of the piston and hole are all taken into consideration while constructing a piston. When designing an engine piston, the following aspects should be taken into account: It must be very durable in order to withstand the immense strain.

- In order for the cylinder to endure inertia forces, it must have lightweight and effective oil seals.
- It must have an adequate bearing area in order to avoid excessive wear.
- Distracting background noise shouldn't be a problem while travelling at high speeds.
- For this reason, thermal and mechanical distortions are uncommon.
- A few more things to keep in mind include making sure that the piston pin is supported properly.

Forces

The following forces act on the piston: There is a lot of inertia due to the piston's high-frequency reciprocating action. A certain amount of friction is created between the cylinder walls and the piston rings during the combustion process. When heated, gases expand.

Many types of engines

Otto and Diesel are two of the most used fuel cycles for internal combustion engines. The Otto cycle is named after Nikolaus Otto, the inventor of the four-stroke engine, who died in 1891. A spark is required to ignite the fuel and air combination in a SI engine before it can run. These engines are referred to as compression ignition because the gasoline is automatically ignited as it is pushed into the combustion chamber (CI). This may be accomplished with either a two- or four-stroke Otto engine.

Noises made by a Piston.

For the piston ring to stay there, the piston has a ring groove across the whole circumference. It's the ring's parallel surfaces that are known as the "ring land". A good seal can only be produced if the piston rings are perfectly aligned between their running surfaces. Radial fit is ensured by the piston ring exerting its own pressure. In addition, the piston ring seals must be kept in good working order.

Figure : Piston Rings

The piston is kept from leaking by the pressure in the combustion chamber acting as a seal. The combustion gases exert pressure on the piston ring, causing it to expand. Chamfered edges may be seen on the running surface of certain piston rings. Even when there are no combustion gas pressures, the chamfered edge of the piston ring causes it to revolve. The fundamental job of the piston is to make things move.

Thermodynamic Optimization of IC Engine Pistons: A Book Review In this scenario, FEM is used. Yes, by Y and R Bhagat as well The thermal characteristics of design 1 and 2 are being tested using an uncoated aluminium silicon alloy diesel piston. ANSYS does a second thermal study on the zirconium-covered piston. Because of the coatings, scientists are studying the pistons' thermal behaviour. The finite element analysis is carried out using design tools. The ultimate objective of our research is to learn more about the process by which heat is transported from the piston to the flame. Using a finite element analytic technique, this thesis shows how mesh optimization may be used to forecast where on a component the greatest stress and strain is occurring. Functionally graded coatings on aluminium and zirconium-coated piston surfaces were studied using an ANSYS commercial software system. Changing the design of the piston's crown, skirt, and sleeve reduces stress on these components. NX/Catia software will be used to generate a structural model of the piston. The finite element analysis is carried out using ANSYS, a CAS tool. When a piston skirt deforms during use, the risk of a fractured piston crown increases. If the piston isn't robust enough to withstand stress concentrations towards the top of the piston, a fracture at point A might spread and produce vertical splitting of the piston. The stress distribution on the piston is greatly affected by the piston's deformation. A strong piston crown is required to reduce stress concentration.

The pistons are what power an engine. Ductile Iron 65-45-12 Pistons and Engineered Aluminum Cast Alloy A390 Pistons Normal engine functioning implies that the crankshaft receives and transmits the energy generated during combustion when the piston receives and transmits the energy from the combustion process. It won't live long if it can't withstand the heat. Internal combustion engines need exact predictions of piston mechanical and thermal behaviour. In addition to the physical properties of mechanical strength and density, wear and thermal expansion parameters must also be considered. A 3-D computer-aided design (CAD) model of the piston is used as a starting point. Before any product is made, FEA software simulates the expected service conditions to guarantee that nothing goes wrong. This method results in faster design and testing, shorter lead times, and a superior product. Using finite analysis, model pistons may be decomposed into an endless number of parts. The entire stiffness of the piston is predicted using a computer algorithm. Foretelling the future is feasible with the information acquired. Positive and negative characteristics are included in material considerations. A material's thermal and mechanical stresses may be predicted using finite element analysis (FEA).

METHODOLOGY

Inventor and ANSYS are used to create a virtual piston in the real world working environment and analyse the piston with boundary restrictions. The following goals were met in the completion of this project.

Inventor can be used to create an IC engine piston.

ANSYS 13.0 is used for the piston's structural and thermal analysis.

The Methodology of the Procedure.

To import a 3D piston model, Hyper Mesh is utilised. An important aspect of the modelling process is the development of meshes and the application of boundary restrictions. RADIOSS is ultimately responsible for solving the problem. Hyper View from Hyper Works, a popular postprocessor, was used to display the outcomes of the solution. The topology optimization criteria are selected. The designable and non-designable space is then built up using a density contour plot created by Hyper View using topological criteria.

INDOOR ENGINES FOR COMBUSTION

An engine utilises thermal energy to convert the chemical energy in fuel into mechanical work. This kind of engine is known as a heat engine because it converts thermal energy into mechanical work. There are two basic types of heat engines: Powered by external combustion Powered by internal combustion engines. Engines with a flammable exhaust pipe (ECIs)

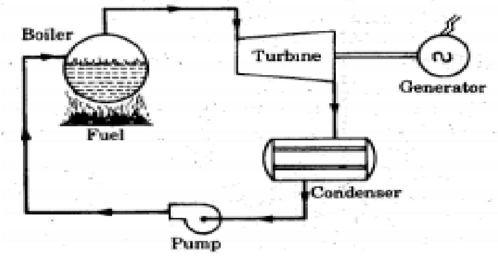


Figure: External combustion engine

Coal-burning steam engines and turbines produce high-pressure steam, which may be used to generate energy in reciprocating engines or steam turbines. The internal combustion engine is shown in the diagram.

Internal combustion engines are divided into two categories: continuous and intermittent. The engine's working fluid, combustion products, is delivered to a prime mover from the engine's combustion chamber. For example: One such example is a gas turbine with an open cycle. Fuel for the turbine is obtained from the combustion chamber's waste products. As seen in Figure, the use of the same working fluid more than once in a cycle is prohibited (below).

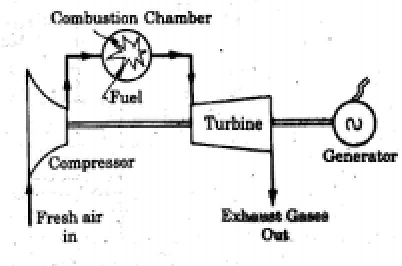
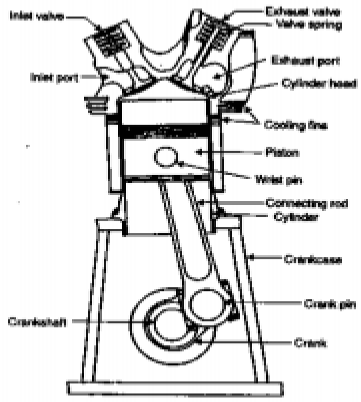


Figure: Continuous IC engine

Only when fuel is required does the fuel burn in an Intermittent Internal Combustion Engine (IICE) (ICIE). Flywheels are utilised to maintain a steady torque output throughout the power stroke.. Cylinder seals develop as pistons go through them, allowing them to be moved. This technique is exploited by compression engines. The connecting rod and crankshaft mechanics transform the revolving piston force into rotational motion [9]. Their popularity has risen dramatically as a result of their extensive use in commercial vehicles. The IC engine is shown in the diagram.



- ✓ Internal combustion engines provide a number of advantages, such as: Streamlined equipment operation.
- ✓ The elimination of auxiliary components such as a boiler, condenser, and feed pump leads in improved operational efficiency. –
- ✓ Making a low-cost investment in the beginning
- ✓ More efficient braking occurs when the cooling system loses less heat.
- ✓ It takes up less space since these units are smaller and more compact in form, making them easier to store.
- ✓ Getting started is simple in a chilly environment.
- ✓ Internal combustion engines have various drawbacks.
- ✓ Solid fuels, which are less costly, cannot be used in I C engines.

- ✓ Liquid or gaseous fuel must meet the appropriate specifications before it may be utilised in the engine.
- ✓ In comparison to other kinds of energy, they are more costly to use.
- ✓ Due to its reciprocating components and sensitivity to mechanical vibrations, I C engines are challenging to balance.

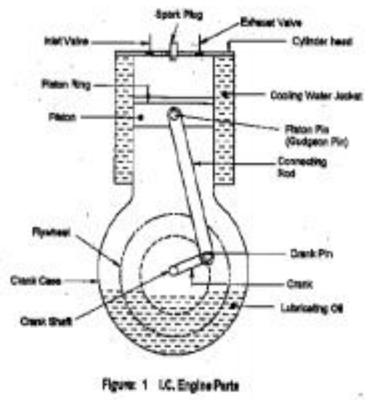


Figure: Crane cahes

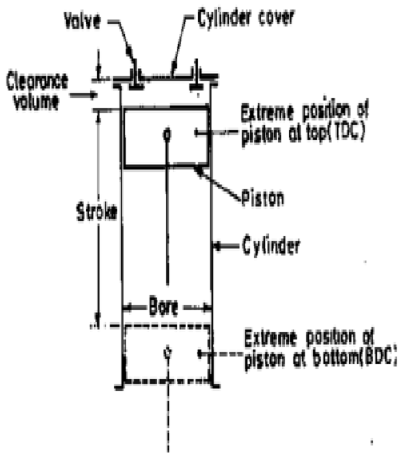


Figure : IC Engine terminologies

DESIGN ANALYSIS

By using the reduced variation calculus developed by Ritz, Courant was able to provide approximate solutions to vibration systems in 1943. In a book published in 1956, M. J. Turner, R. W. Clough, H. C. Martin, and L. J. Topp expanded the definition of "numerical analysis." Also in attendance were academics from the following four institutions: Structures with a high degree of complexity were investigated in the essay. FEM was only available on expensive mainframe computers in the aerospace, automobile, military and nuclear industries until the early 1970s. FEA can now attain previously inconceivable levels of accuracy since computers have gotten significantly more inexpensive and processing power has soared. Supercomputers are now capable of properly predicting a broad variety of variables.

Analyze structurally

Structural analysis investigates structures and its constituent parts, as well as the effects of stresses on physical structures. Structures such as buildings, bridges, autos, machinery, and clothes may all be the subject of investigation.. Structure analysis is an applied mechanics and applied mathematics combination that is used to calculate the deformations, internal pressure and stress, support response, acceleration, structural stability of a structure. Analyses may be utilised instead of physical testing to evaluate whether a structure is acceptable for occupancy. Structural analysis is a need while undertaking any construction project.

MATERIALS AND THEIR PROPERTIES

For piston:

	Al alloy 4032	AISI4340 Alloy Steel	Titanium Ti-6Al-4V
Poisson ratio	0.35	0.28	0.342
Modulus of elasticity(GPa)	79	210	113.8
Thermal conductivity (w/m k)	155	44.5	6.7
Ultimate tensile strength MPa	380	745	950
Yield tensile strength MPa	315	470	880
Density g/cc	2.68	7.8	4.43

For piston ring:

	Ductile Nodular Spheroidal cast iron	ASTM grade 50 (ISO grade 350, EN – JL 1060) Grey cast iron
Poisson ratio	0.275	0.26
Modulus of elasticity (GPa)	176	157
Thermal conductivity (w/m k)	33	46
Ultimate tensile strength MPa	414 – 827	362
Yield tensile strength (MPa)	240 – 621	228
DENSITY g/c.c	7.2	7.1

The piston and piston rings are designed in accordance with machine design and design data book methods and specifications. CATIA V5R20 is used to model the piston and the piston ring, as shown in Fig.

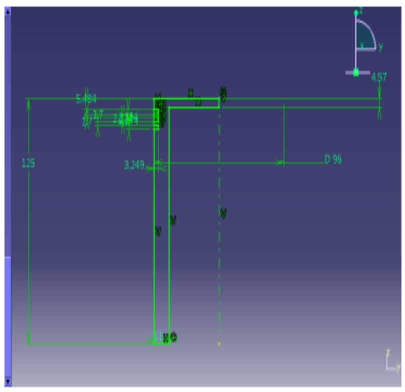


Fig. Piston Drawing and Dimensions

OPTIMIZATION OF PISTON

Creating an accurate finite element model was the first step in devising a strategy for optimising the system. A primary objective of the optimization was to lower the mass of the piston. The major objective is as follows: Reduce the system's weight.

According to the situation:

Maximum If Von is under any kind of stress, she will snap.

Restriction on production

A static structural analysis was conducted to guarantee that the maximum von misses stress was not exceeded and the factor of safety was kept above 1.5.

- ❖ The Radial Thickness of the Ring makes material removal impossible.
- ❖ Axial Thickness of the Ring
- ❖ The Maximum Thickness of the Barrel
- ❖ The length of the High Lands
- ❖ The distance between the two rings

MODELING AND TECHNOLOGY DEVELOPMENT CLASS

A detailed description of how something works.

Engine Type	Air-cooled, 4-stroke single cylinder OHC
Displacement	97.2 cc
Max. Power	5.66 KW ,@ 5000 rpm
Max. Torque	7.130 N-m @ 2500 rpm
Compression Ratio	9.9 : 1
Starting	Kick Start / Self Start
Ignition	DC - Digital CDI
Bore	50 mm
Stroke	49 mm

THEORETICAL CALCULATION FOR PISTON

1) Torque

$P = \frac{2\pi NT}{60}$

We know that p=5.6 kw

$5.6\times e^3 = 2\times 3.14\times 7500\times T / 60$

T=7.130 N-m

2) Diameter of piston

$\pi r^2 h = cc$

Cylinder area = displacement

We know that displacement so to find diameter of piston

Diameter D = 2×r

D = 2*0.025 m =0.05m=50mm

3) Cylinder inside pressure

Pressure = force/area (F/A)

Force =power/velocity (P/V)

We know that power

Velocity =2LN/60=2×0.049*5000/60= **8.16M/S**

Force $=5.6e^3/8.16 =$ **686.274N**

P = F/A

Area $= \pi r^2 = 3.14\times (0.025)^2 = 1.934E^{-3}\ M^2$

$P=686.27/1.934E^{-3} =0.34953$Mpa (minimum)

Maximum pressure =15× Pmin

P max =15× 0.34953 =5.24 Mpa

Max pressure = 5.24 Mpa

SOFTWARE REQUIREMENTS

Compression Stroke:

As the piston moves from bottom to top dead centre, the air taken at atmospheric pressure during the suction stroke is compressed to high pressure and temperature. This may be seen on the P-V diagram via the curve BC. A fuel injector accurately injects a predefined amount of fuel into the hot compressed air just before the conclusion of this stroke in order to maximise efficiency. There is a constant pressure on the CD line, which means the fuel is burning properly. During this stroke, all of the engine's valves, including intake and exhaust, are closed.

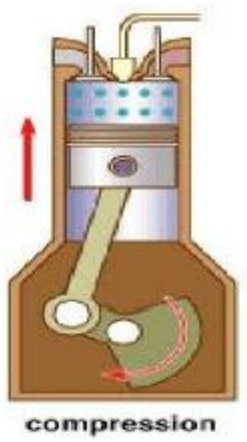


Figure : Compression Stroke

Working Stroke:

Combustion heat causes the expansion of gases, which creates a pressure on the piston. So, the piston travels from its highest point to its lowest point in this stroke and thus does some work. During this stroke, both the intake and exhaust valves are closed. The curve DE [13] depicts the gas's growth.

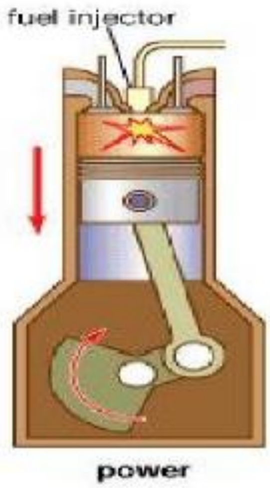


Figure : Power stroke

PISTON DESIGN

As outlined in machine design manuals and data sheets, the piston is created using a predetermined technique and specification. SI Units are used to compute the dimensions. Temperatures, stresses, strains, lengths, diameters, and thicknesses of piston and hole, as well as other characteristics, are taken into account [2,5,7].

- Considerations for the design of a piston
- The following factors should be considered while creating an engine piston:
- If it is to resist the immense strain, it will need to be very strong.
- Because of the inertia forces, it must be light in weight.
- If it works, the cylinder should have an effective seal.
- Bearing area should be adequate to avoid excessive wear.
- High-speed reciprocation with little noise is required.
- Ideally, it should be built with enough rigidity to endure both thermal and mechanical changes.
- It should be able to support the piston pin adequately.

In ANSYS

Ansys analysis is introduced in this section.
It is a product analysis programme that is extensively distributed and popular commercial CAE package, and it is frequently used by designers and analysts in sectors such as automobiles and electronics.

Space

Secondly, automobiles
The third step is the production of goods. Nuclear power The fifth point is electronic. In addition to biomedical..., etc., Simulating design performance on the desktop is made possible by Ansys' simulation solutions. As a result, the whole product development cycle — from concept design through performance validation — may be completed quickly, efficiently, and affordably.

Analytical Concepts:

The programme employs the Finite Element Method (FEM). Engineers use FEM to analyse their designs numerically. A computer-implemented version of FEM is widely acknowledged as the standard analytical approach. Many basic forms known as elements are used to break up the model, essentially replacing a big issue with a series of tiny problems that must be addressed concurrently.

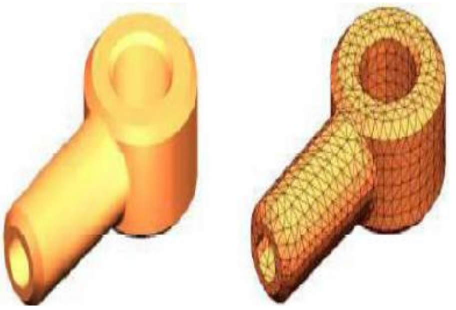


Fig (1) CAD model of a (2) Model subdivided into small pieces

Static Analysis

ANSYS software's FEM finite elements were utilised to conduct a thermal and static analysis of pistons. For ANSYS simulation, the geometry of solid works is split down into components. This is where all of the components are linked together. When it comes to the thermal and structural analysis of piston solid works, we rely on FEA. By employing computer software, the piston may be pre-programmed. When the modelling process is complete, IGES files saved in SolidWorks are imported into ANSYS software for finite element analysis.

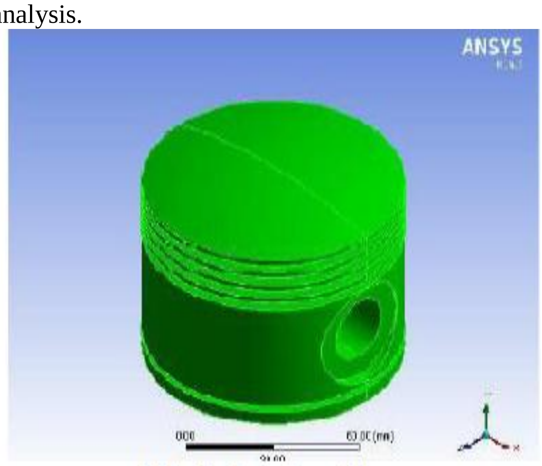


Fig: Static Analys on Piston:

Because of the piston pin, the piston pin and connecting rod do not move in any manner. Piston movement has been completely paralysed by the pin holes (DOF)
In the Thermal Transfer Calculations, the COEFFICIENTS are .
Turbulent heat transfer in cylinders is compared to the heat transfer from combustion gases.

Rem Prn is Nu's inverse.

He stated he utilised Gunter F.Hohenberg's equation(1) to connect the cylinder volume and the piston diameter in the equation (1). Calculating heat transfer coefficients at the piston crown surface is based on equation (2).

A Piston's Heat Transfer Measurements

Closest to the throne It is feasible to compute the heat transfer coefficient for a segment of a piston's undercrown surface using the correlation between the Nusselt number and other surface features, such as ribs and pin bosses.

Stability of the Piston:

This study found that the side thrust force had a significant influence on piston deformation, despite the fact that it had a little effect on pressure or inertia forces. The piston crown is subjected to a pressure of 13.65 MPa.

Searching for information about each element's features and characteristics.

FEA is used to examine the piston's stresses and trouble locations. An aluminium alloy is employed in the FEA piston's construction since that metal is also used for optimization. Pistons may be studied using a thermo-mechanical analysis. A table of characteristics for aluminium alloys is provided in Table 3. [8]

Improved response time.

The stress amplitudes were kept within acceptable limits for the compression gas load and temperature supplied to the pistons via a parametric optimization approach that lowered piston mass. This image depicts a more refined piston. The following is the assertion expressed in mathematical terms: There are two key goals: to reduce weight and to increase the safety.

Up to the greatest amount of von-mises stress permitted or intended for multiple safety considerations, there is no limit. Various engine components are constrained geometrically (iii) You may delete or add material because of the following reasons: Thickness of the T2 Axial Ring. The length of the topland is expressed using the equation b1. Thickness t3 of the barrel at its thickest point. Piston crown thickness (tH). The ring's radial thickness, t1.

SIMULATION RESULTS

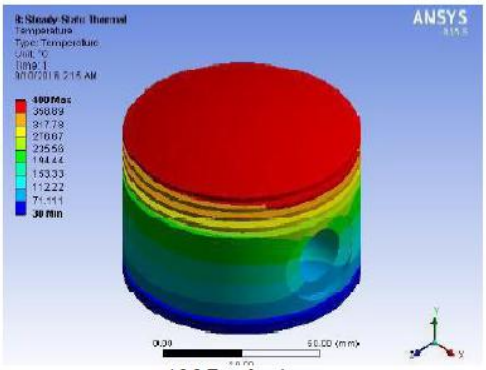


Figure: For aluminium

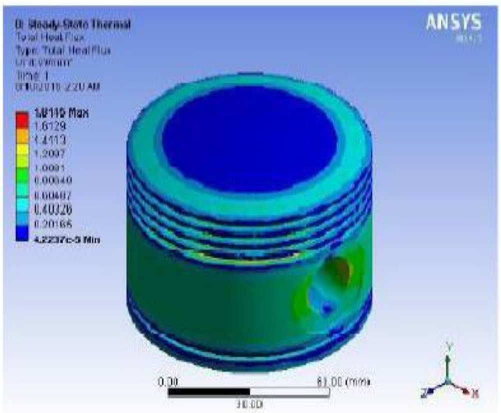


Fig: For grey cast iron

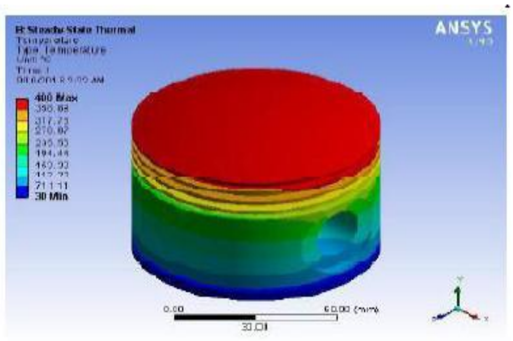


Figure :For al-sic graphite

Dissecting a complex problem or topic may help you develop a better comprehension of it. Thermal Analysis and Static Analysis in the current model are referred to as "coupled field analysis." A meshed component is used to study the thermal stresses on the piston. Heat conduction and convection may have an impact on the piston's top component. The images below illustrate the deformation and vonmisses stresses before and after optimization.

Deformation and Vonmisses Stress before Optimization

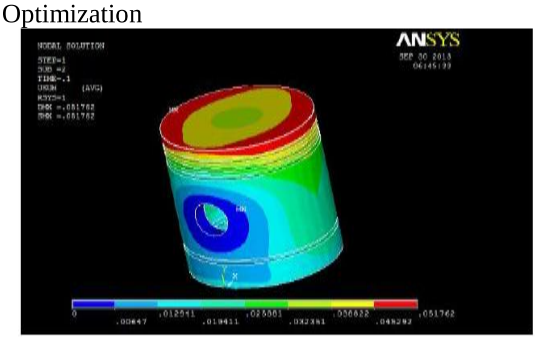


Figure : Resultant Deformation

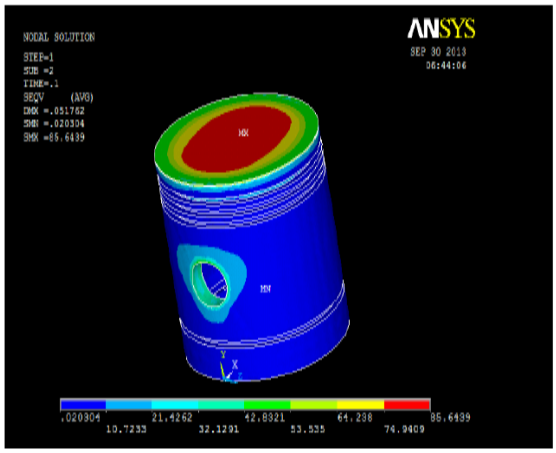


Figure : Vonmisses Stress

Deformation and Vonmisses Stress after Optimization

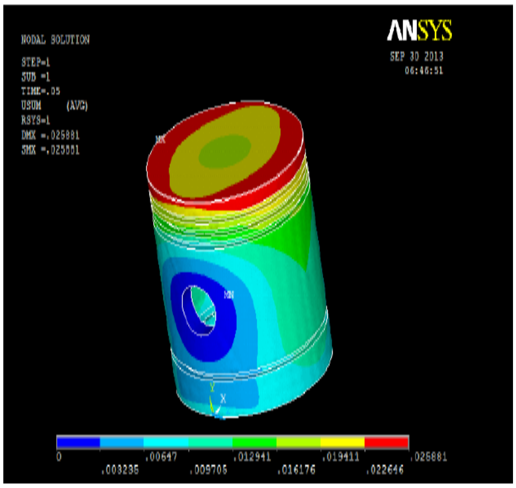


Figure : Resultant Deformation

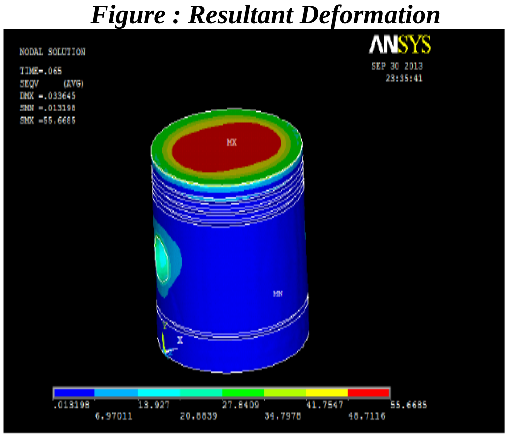


Figure : Vonmisses Stress

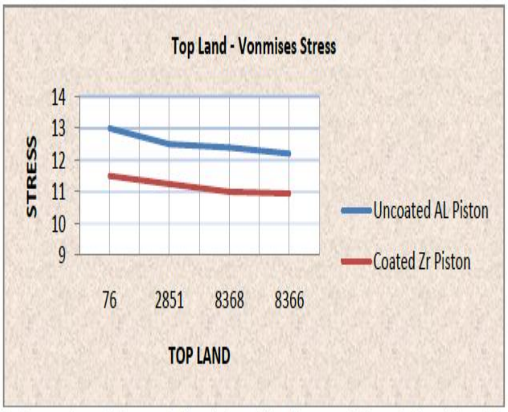


Figure : Comparison of Uncoated Aluminium Alloy Piston and Coated Aluminium Alloy Piston

The optimized values after optimization using ANSYS are given in the following Table

S. no	Parameter	Before optimisation	After optimisation	Design consideration
1	Radial thickness of the ring (t_1)	5.24 mm	3.46 mm	4 mm
2	Axial thickness of the ring(t_2)	5 mm	3.52 mm	4 mm
3	Maximum thickness of the barrel (t_3)	14.34 mm	9.08 mm	9 mm
4	Width of the top land(b_1)	10.84 mm	9.36 mm	10 mm
5	Width of the ring lands(b_2)	4 mm	3.24 mm	3 mm
6	Vonmisses stress	85.6439 Mpa	55.6685 Mpa	56-86 Mpa
7	Deflection	0.051762 mm	0.025884 mm	0.025884 mm

Table : Results

In this experiment, the 152 mm length and 140 mm diameter are considered constants. In terms of performance, it doesn't matter how long or wide a piston is. The radial thickness of the piston has been extensively damaged due to its size and high temperature and heat flow. The first reading was 5.24mm, and the final reading was 3.46mm. Measurements like this are usually rounded to the next greatest whole number throughout the design process. A rise in piston ring thickness from 5 mm to 3.52 mm was caused by the increased heat and stress caused by the grooves on the piston. In this case, 4 millimetres is the next largest quantity. Optimized barrels have a maximum thickness of 9.08mm, which is rounded to the next largest figure possible, 14.34mm (i.e. 10mm). Pressure applied to a piston's head (the top), which causes it to take on a bowl-like form, was previously 10.84mm. After rounding to the nearest millimetre, the result is 9.36mm. This is a crucial factor to take into account throughout the design phase. Pressure and heat applied to rings in grooves, ranging in width from 4 mm to 6 mm, alter the width of adjacent lands. The final result of optimization is 3.24 mm, rounded up to 3 mm.

CONCLUSION

Here, you'll find a thorough examination of single-cylinder gasoline engines' essential concepts and design techniques. The findings of this analytical method are almost identical to those that are currently used. As a result of the piston's fast construction and subsequent improvement, it may be employed in a variety of ways. It's not necessary to consider many details while making the pistons for an engine.

IN THE PRESENT DAY.

You may use the paper's dimensions to conduct an ANSYS analysis on the model you constructed. When determining whether or not the design is safe, this will provide an idea of how to further lower the weight of the piston (i.e. work towards the reduction of weight). It is possible to increase the piston's strength and light weight by altering its composition.

REFERENCES

[1] Cuddy, M. R. & Wipke, K. B. (1997), Analysis of Fuel Economy Benefit of Drive train ybridization.http://www.nrel.gov/vehiclesandfuels/vsa/pdfs/22309.pdf (National Renewable Energy laboratory).

[2] F.S. Silva (2006) Fatigue on engine pistons – A compendium of case studies. Engineering Failure Analysis, 13 pp(480–492).

[3] Ekrem Buyukkaya, Muhammet Cerit (2007) Thermal analysis of a ceramic coating diesel engine piston using 3-D finite element method. Surface and Coatings Technology 202, 2 pp (398–402).

[4] Dr.Najim A.Saad, Dr. Haitham R. Abed Ali, Dr. Hayder Shakir Abudalla, (2008), numerical analysis of the thermal –stresses of a petrol engine piston with different materials, The Iraqi Journal for Mechanical and Material Engineering, 8, 3 pp (249-256).

[5] Gudimetal P, Gopinath C.V, (2009) Finite Element Analysis of Reverse Engineered Internal Combustion Engine Piston, AIJSTPME, 2, 4 pp (85-92).

[6] Yanxia Wang, Yongqi Liu,Haiyan (2010), Simulation and Analysis of Thermo Mechanical Coupling Load and Mechanical Dynamic Load for a Piston; IEEE, pp (106-110).

[7] Wu, Yi Zeng, Dongjian Feng, Zhiyuan, (2010) Finite Element Analysis for the Thermal Load of Piston in a Dimethyl Ether Fueled Diesel Engine, IEEE.

[8] Mesut Durat, Murat Kapsiz, Ergun Nart, Ferit Ficici & Adnan Parlak, (2012), The effects of coating materials in spark ignition engine design; Materials & Design, 36 PP (540-545).

[9] Vinod Junju , M.V. Mallikarjun and Venkata Ramesh Mamilla, (2012), Thermo mechanical analysis of diesel engine piston using ceramic crown ; International Journal of Emerging trends in Engineering and Development 5, 2, pp (22- 29).

[10] R. S. Khurmi, J. K. Gupta (2005); Machine Design; 14th ed.; Eurasia Publishing House (Pvt.) Ltd., Ramnagar, New Delhi.

[11] Ajeet Kumar Rai and Ashish Kumar, "A Review on Phase Change Materials & Their Applications", International Journal of Advanced Research in Engineering & Technology (IJARET), Volume 3, Issue 2, 2012, pp. 214 - 225, ISSN Print: 0976-6480, ISSN Online: 0976-6499.

[12] Ajeet Kumar Rai, Richa Dubey, Shalini Yadav and Vivek Sachan, "Turning Parameters Optimization for Surface Roughness by Taguchi Method", International Journal of Mechanical Engineering & Technology (IJMET), Volume 4, Issue 3, 2013, pp. 203 - 211, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.

[13] Yuvaraj P. Ballal, Manjit M. Khade and Ajit R. Mane, "Comparison of Performance of Coated Carbide Inserts with Uncoated Carbide Inserts in Turning Gray Cast Iron", International Journal of Mechanical Engineering & Technology (IJMET), Volume 4, Issue 2, 2013, pp. 392 - 400, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.

[14] Haider Shahad Wahad, Ajeet Kumar Rai and Prabhat Kumar Sinha, "Modeling and Analysis of Involute Helical Gear using Catia5 and Ansys Softwares", International Journal of Mechanical Engineering & Technology (IJMET), Volume 4, Issue 5, 2013, pp. 182 - 190, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.

