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# Finite element analysis was used to do thermal investigation and optimization of the IC engine piston.

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**Abstract:**

The stress distribution of the seizure on piston four stroke engine by using FEA. Piston modelling is performed by using Computer Aided Three dimensional interactive Application (CATIAv5) software. The main objective is to investigate and analysis the thermal stress distribution of piston at the real engine condition during combustion process. The mesh optimization with using finite element analysis technique to predict the higher stress and critical region on the component. The main emphasis is placed on the study of thermal behaviour of functionally graded coatings obtained by means of using a commercial code. The optimization is carried out to reduce the stress concentration on the upper part of the piston i.e (piston head/crown and piston skirt and sleeve). With using CATIAv5 software the structural model of a piston will be developed. Furthermore, thermal analysis and optimization is performed by Ansys software.

**Keywords:** CATIAv5, ANSYS

## INTRODUCTION

Automobile components are in great demand these days because of increased use of automobiles. The increased demand is due to improved performance and reduced cost of these components. R&D and testing engineers should develop critical components in shortest possible time to minimize launch time for new products. This necessitates understanding of new technologies and quick absorption in the development of new products. A piston is a component of reciprocating IC-engines. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings.

In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod. As an important part in an engine, piston endures the cyclic gas pressure and the inertial forces at work, and this working condition may cause the fatigue damage of piston, such as piston side wear, piston head/crown cracks and so on.

## EXPERIMENTAL PROCEDURE

The complete experiment is done using design and development tools namely CATIA and ANSYS. It is normally works on the basis of finite element approach.

### Finite element approach

Finite element approach is normally through the usage of software for designing and analysis. Software such as CATIA and ANSYS works on the basis of finite element methods.

### Piston design

The piston is designed according to the procedure and specification which are given in machine design and data hand books. The dimensions are calculated in terms of SI Units. The pressure applied on piston head, temperatures of various areas of the piston, heat flow, stresses, strains, length, diameter of piston and hole, thicknesses, etc., parameters are taken into consideration.

### Design considerations for piston

In designing a piston for an engine, the following points should be taken into consideration:

- It should have enormous strength to withstand the high pressure.
- It should have minimum weight to withstand the inertia forces
- It should form effective oil sealing in the cylinder.
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**Producer for piston design parameters**

The procedure for piston designs consists of the following steps:

- Thickness of piston head (tH)
- Heat flows through the piston head (H)
- Radial thickness of the ring (t1)
- Axial thickness of the ring (t2)
- Width of the top land (b1)
- Width of other ring lands (b2)

**Formulae**

Following are some of the formulae used to find the parameters of the piston

**Thickness of Piston Head (tH)**

$$t = D\sqrt{\frac{3}{16}} * \sqrt{\frac{P}{\sigma t}}$$

Where

P = maximum pressure in N/mm²

D = cylinder bore/outside diameter of the piston in mm.

Here the material is a particular grade of AL-Si alloy whose permissible stress is 50 Mpa- 90Mpa before calculating thickness of piston head, the diameter of the piston has to be specified. The piston size that has been considered here has an L*D specified as 150*138.

**Heat Flow through the Piston Head (H)**

The heat flow through the piston head is calculated using the formula

$$H = 12.56 * t * K * (Tc \;\; Te) \frac{KJ}{sec}$$

Where,

K = Thermal conductivity of material which is 174.15W/mk

Tc = temperature at centre of piston head in °C

Te = temperature at edges of piston head in °C.

**Radial Thickness of Ring, t1 = D√3pw/σt**

Where,

D = cylinder bore in mm

Pw = pressure of fuel on cylinder wall in N/mm² Its value is limited from 0.025N/mm² to 0.042N/mm². For present material σt 90Mpa

**Axial Thickness of Ring (t2)**

The thickness of the rings may be taken as

**t2 = 0.7t1 to t1**

Let assume t2 = 5mm

Maximum axial thickness (t2)

t2= D/10*nr Where nr = number of rings

**Width of the top land (b1)**

The width of the top land varies from **b1= t to t*1.2**

**Maximum Thickness of Barrel (t3)**

**t3=0.03*D+b+4.5mm**

Where,

b = Radial depth of piston ring groove

**b = t1+0.4**

The following are the sequence of steps in which the piston is modelled using CATIA.

- Drawing a half portion of piston
- Exiting the sketcher
- Developing the model
- Creating a hole
- Applying fillets

It was then imported to ANSYS 14.5. For analysis and optimization. Specifications of piston before optimization.

**PISTON MODELLING**

From the above expressions the below tabulated parameters are calculated.

Table.1: Design dimensions

| S.NO | DESIGN 1- DIMENSIONS | SIZE IN mm |
|---|---|---|
| 1 | Length of the piston (L) | 150 |
| 2 | Cylinder bore/Outside diameter of of the piston(D) | 138 |
| 3 | Radial thickness of the ring (t1) | 4.36 |
| 4 | Axial thickness of the ring (t2) | 3.49 |
| 5 | Maximum thickness of the barrel (t3) | 13.48 |
| 6 | Width of the top land (b1) | 9.89 |
| 7 | Width of the other ring lands (b2) | 2.62 |

The dimensions for the piston are calculated and these are used for modelling the piston in CATIA V5 R20.Thus, a symmetric model is developed using the above dimensions. The piston model is drawn in the sketch and is converted in to3-D element in part design. The piston modeled in CATIA is directly imported in to ANSYS 14.5 for further analysis and optimization.

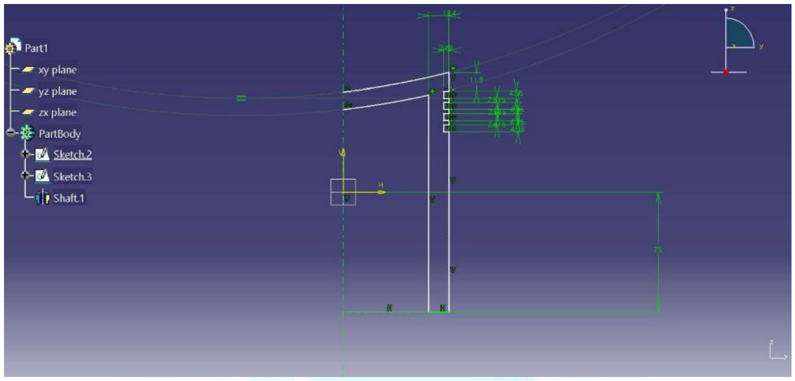


Fig.1: Piston was modelled using CATIYA V5 R20

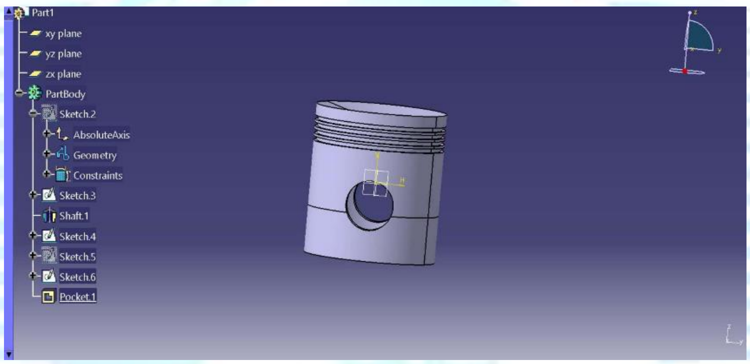


Fig.2: Piston is executed in part design for 3-D

**The CAD and FEA of Piston**

The design of the piston starts with the definition of the piston geometry using 3D CAD software This 3D CAD geometric model is then imported to FEA software and analysed under the predicted service conditions before anything is made. That speeds up the design and testing process, reduces the lead time to create new pistons designs, and produces a better product. The idea behind finite element analysis is to divide a model piston into a fixed finite number of elements.

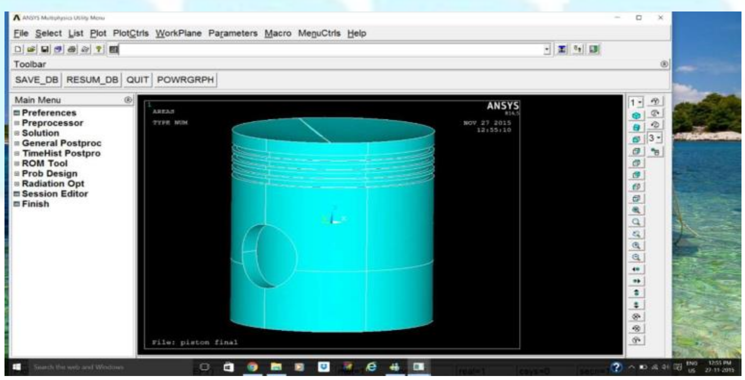


Fig.3: Imported model of piston in ANSYS

Analysing the data it is possible predict how the piston will behave in a real engine and allows the engineer to see where the stresses and temperatures will be the greatest and how the piston will behave. Analysis of the piston is done to optimize the stresses and minimize the weight using ANSYS. The mathematical model of optimization is established firstly, and the FEA is carried out by using the ANSYS software.

**Meshing of piston before optimization**

Meshing is probably the most important part in any of the computer simulations; because it can show drastic changes in results you get. Meshing means you create a mesh of some grid-points called 'nodes 'Element used is 20 node Tetrahedron named soilid90. The element size is taken as 5, then total number elements were 57630 and nodes were 91176 found in meshed model. Meshing is done using ANSYS. Following figure represents the meshed product of the piston.

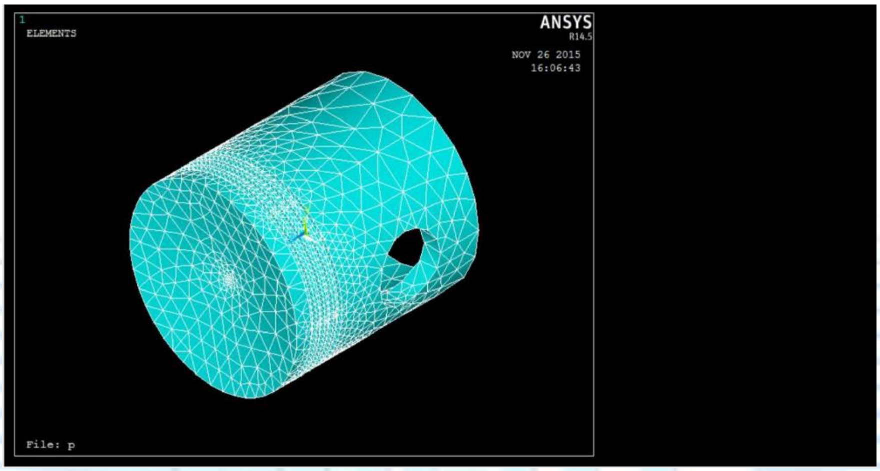


Fig.4: Meshing model of piston

**Thermal and geometric properties of the piston material**

It is important to calculate the piston temperature distribution in order to control the thermal stresses and deformations within acceptable levels. A lubricant film fills the clearance between the surfaces. Most of the Internal Combustion (IC) engine pistons are made of an aluminum alloy which has a thermal expansion coefficient, 80% higher than the cylinder bore material made of cast iron.

Table.2: Thermal and Geometric properties

| **roperty** | **Aluminium Alloy** |
|---|---|
| Youngs modulus | 70e3 MPa |
| Poisons ratio | 0.33 |
| Thermal conductivity | 234 W/mK |
| Co-eff of Thermal expansion | 23e-6/K |

**ANALYSIS**

The boundary conditions for mechanical simulation were defined as the pressure acting on the entire piston head surface. The temperature load is applied on different areas and pressure applied on piston head. The regions like piston head and piston ring regions are applied with large amount of heat (160°C- 200°C). The convection values on the piston wall ranges from 232 W/mK to 1570 W/mK, and the working pressure is 2 Mpa.

**Optimization of piston**

1. Maximum Vonmisses stress<Allowable or design stress

2. Manufacturing constraints

3. After carrying out static structural analysis the stresses in each loading conditions were studied and then area where excess material can be removed were decided so that maximum Vonmisses stress does not exceed allowable and factor of safety is kept above 1.5.

4. Following reasons where scope for material removal.

- Radial Thickness of the ring
- Axial Thickness of the ring
- Maximum Thickness of the Barrel
- Width of other ring lands
- Width of the top land

**NALYSIS,RESULTS AND DICUSSIONS**

Table.3: Design specifications Piston model after

| S.No | Design 2 Dimensions | Size in mm |
|---|---|---|
| 1 | Length of the piston (L) | 150 |
| 2 | Diameter of the piston (D) | 138 |
| 3 | Radial thickness of the ring (t1) | 6.17 |
| 4 | Axial thickness of the ring (t2) | 4.93 |
| 5 | Maximum thickness of barrel | 15.21 |
| 6 | Width of the top land (b1) | 13.85 |
| 7 | Width of the other ring lands (b2) | 3.697 |

Analysis is the process of breaking a complex topic or substance into smaller parts to gain a better understanding of it. The current model is undergone Thermal Analysis and followed by Static Analysis, together called as Coupled Field Analysis. The meshed component is analysed to find the thermal stresses of the piston.. The following images are shown for resulted deformation and vonmisses stresses before and after optimization.

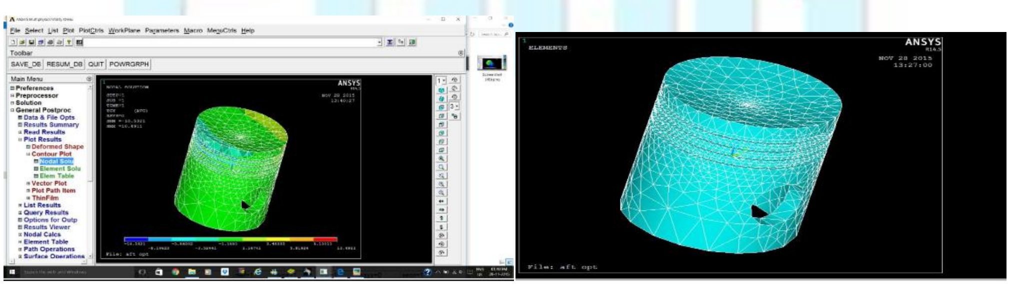


Fig.7: Mashed product of the after optimization

The length 150 mm and the diameter 138 mm are assumed to be constant. It is not considerable that the variations in piston length and diameter of the piston. The radial thickness of the piston has affected more as it is very small in size and the temperature and heat flow are very high to this size of thickness. Before optimization value is given as 4.36mm and obtained after optimization is 6.17mm. This is rounded to next highest value. The axial thickness of the piston ring before optimization is 3.49mm it is changed to 4.93mm after optimization, since the more and more heat and stress applied through groves as it is very near to the head of the piston. This is rounded to next highest value. The maximum thickness of the barrel before optimization is 13.4mm has much affected in variation of size after applying pressure and temperature loads and is changed to 15.21 and rounded to next highest value. The initial value i.e., before optimization is 8.91mm and is changed after applying pressure which is directly applied on the head i.e., top of the piston as a result the shape of the piston on top will become just like a bowl. The value after optimization is 9.8mm and it is rounded to 10mm. This value is considerable for design. The width of the other lands i.e., near piston rings are 2.616mm in size and is changed due to pressure and heat applied on rings through groves. The value after optimization is 3.7mm.

**CONCLUSIONS**

The main aim of this proposed model is to improve quality of piston to withstand high thermal and structural stresses and at the same time reduce stress concentration the upper end of the piston. The FEA is carried out for standard diesel engine piston and the result of analysis is compared for maximum stress. Different alloys of aluminum are tested for maximum stiffness at operating thermal and structural stress using FEA.

Piston skirt may appear deformation at work, which usually causes crack on the upper end of piston head. Due to the deformation, the greatest stress concentration is caused on the upper end of piston, the situation becomes more serious when the stiffness of the piston is not enough, and the crack generally appeared at the point A which may gradually extend and even cause splitting along the piston vertical. The stress distribution on the piston mainly depends on the deformation of piston. Therefore, in order to reduce the stress concentration, the piston crown should have enough stiffness to reduce the deformation.

The FEA is carried out for standard piston model used in diesel engine and the result of analysis indicate that the maximum stress has changed from 45 Mpa. to 29 Mpa. And biggest deformation has been reduced from 0.1006 mm to 0.0439 mm.

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