ABSTRACT

The main objective of this research work is to investigate and analyze the stress distribution of piston at actual engine condition. In this paper pressure analysis, thermal analysis and thermo-mechanical analysis is done. The parameter used for the analysis is operating gas pressure, temperature and material properties of piston. In I.C. Engine piston is most complex and important part therefore for smooth running of vehicle piston should be in proper working condition. Piston fail mainly due to mechanical stresses and thermal stresses. Analysis of piston is done with boundary conditions, which includes pressure on piston head during working condition and uneven temperature distribution from piston head to skirt. The analysis predicts that due to temperature whether the top surface of the piston may be damaged or broken during the operating conditions, because damaged or broken parts are so expensive to replace and generally are not easily available. The CAD model is created using PRO-E software. CAD model is then imported into ANSYS software for geometry and meshing purpose. The FEA performed by using ANSYS12.

Keywords: Piston, PRO-E, ANSYS12.

1. INTRODUCTION

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. 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 cracks and so on. So there is a need to optimize the design of piston by considering various parameters in this project the parameters selected are analysis of piston by applying pressure force acting at the top of the piston and thermal analysis of piston at various temperature in various stroke. This analysis could be useful for design engineer for modification of piston at the time of design. In this project we determine the various stress calculation by using pressure analysis, thermal analysis and thermo-mechanical analysis form that we can find out the various zones or region where chances of damage of piston are possible. From analysis it is very easy to optimize the design of piston. The main requirement of piston design is to measure the prediction of temperature distribution on the surface of piston which enables us to optimize the thermal aspects for design of piston at lower cost. Most of the pistons are made of an aluminum alloy which has thermal expansion coefficient, 80% higher than the cylinder bore material made of cast iron. This leads to some differences between running and the design clearances. Therefore, analysis of the piston thermal behavior is extremely crucial in designing more efficient compressor. Good sealing of the piston with the cylinder is the basic criteria to design of the piston. Also to improve the mechanical efficiency and reduce the inertia force in high speed machines the weight of the piston also plays major role. To allow for thermal expansion, the diameter of the piston must be smaller than that of the cylinder. The necessary clearance is calculated by estimating the temperature difference between piston and cylinder and considering the coefficient of thermal expansion of piston.

2. MATERIAL FOR PISTONS

The most commonly used materials for pistons of I.C. engines are cast iron, aluminum alloy (cast aluminum, forged aluminum), cast steel and forged steel.

a) For a cast iron piston, the temperature at the centre of the piston head (TC) is about 425°C to 450°C under full load conditions and the temperature at the edges of the piston head (TE) is about 200°C to 225°C.

b) For aluminum alloy pistons, TC is about 260°C to 290°C and TE is about 185°C to 215°C.
3. ANALYTICAL CALCULATION FOR PISTON

Analytical calculations are done for cast iron piston. For doing analytical calculation material properties and dimensional information should be known and so all the parameters consider for design of piston are calculated by using one analytical problem.

Design Considerations for a 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.
- It should provide sufficient bearing area to prevent undue wear.
- It should have high speed reciprocation without noise.
- It should be of sufficient rigid construction to withstand thermal and mechanical distortions.
- It should have sufficient support for the piston pin.

Procedure for Piston Design
The procedure for piston designs consists of the following steps:

(i). Thickness of Piston Head (tH):
The piston thickness of piston head calculated using the following Grashoff’s formula,

\[ t_H = 0.433 \times D \times \sqrt{\frac{P_{\text{max}}}{f_t}} \]

Where,
- \( P \) = maximum pressure in N/mm²
- \( D \) = cylinder bore/outside diameter of the piston in mm.
- \( f_t \) = permissible tensile stress for the material of the piston.

For CI, \( f_t \) may be taken as 37.5 N/mm²

Here the material is a particular grade of AL-Si alloy whose permissible stress is 50 Mpa- 90 Mpa 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 152*140.

(ii). Heat Flow through the Piston Head (H):
The heat flow through the piston head is calculated using the formula

\[ H = 12.56 \times t_H \times K \times (T_c - T_e) \text{ KJ/Sec} \]

Where,
- \( K \) = thermal conductivity of material which is W/m²k
- \( T_c \) = temperature at centre of piston head in °C.
- \( T_e \) = temperature at edges of piston head in °C.

(iii). Radial Thickness of Ring (t1)

\[ t_1 = D \times \sqrt{\frac{3P_w}{f_t}} \]

Where,
- \( D \) = cylinder bore in mm
- \( P_w \) = pressure of fuel on cylinder wall in N/mm². Its value is limited from 0.0245N/mm² to 0.042N/mm². For present material, \( \sigma_t \) is 90Mpa

(iv). Axial Thickness of Ring (t2)
The thickness of the rings may be taken as

\[ t_2 = 0.7t_1 \text{ to } t_1 \]

Minimum axial thickness (t2)

\[ t_2 = \frac{D}{10} * z \]

Where \( z \) = number of rings

(v). Width of the top land (b1)
The width of the top land varies from

\[ b_1 = t_H \text{ to } 1.2 \times t_H \]
(vi). Width of other lands (b2)
Width of other ring lands varies from

\[ b2 = 0.75 \times t2 \text{ to } t2 \]

(vii). Maximum Thickness of Barrel (t3)

Where, 
\[ b = t1 + 0.4 \]

STRESS CALCULATION
1. Stress on Piston Crown

\[ 6b = \frac{3pd^2}{16tH^2} \]

2. Thermal Stress,

\[ 6t = E \times \text{Coefficient of thermal Expansion} \times \text{Temp. Difference} \]

3. Thermo-mechanical Stress,

\[ 6tm = 6b + 6t \]

4. Design specification for piston:

<table>
<thead>
<tr>
<th>S No</th>
<th>Design1 - Dimensions</th>
<th>Size in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Length of the Piston(L)</td>
<td>130</td>
</tr>
<tr>
<td>2</td>
<td>Cylinder bore/outside diameter of the piston(D)</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>Radial thickness of the ring (t1)</td>
<td>3.5</td>
</tr>
<tr>
<td>4</td>
<td>Axial thickness of the ring (t2)</td>
<td>3.0</td>
</tr>
<tr>
<td>5</td>
<td>Maximum thickness of barrel (t3)</td>
<td>11.4</td>
</tr>
<tr>
<td>6</td>
<td>Width of the top land (b1)</td>
<td>18</td>
</tr>
<tr>
<td>7</td>
<td>Width of other ring lands (b2)</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Allowable stress for Cast Iron (from design data book) = 82.0 to 100 N/mm²

5. Material Properties of Piston material

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Unit</th>
<th>Cast Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus of Elasticity</td>
<td>MPa</td>
<td>100×10³</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>--</td>
<td>0.27</td>
</tr>
<tr>
<td>Tensile Yield Strength</td>
<td>MPa</td>
<td>--</td>
</tr>
<tr>
<td>Tensile Ultimate Strength</td>
<td>MPa</td>
<td>140</td>
</tr>
<tr>
<td>Density</td>
<td>Kg/m³</td>
<td>7200</td>
</tr>
<tr>
<td>Coefficient of Thermal Expansion</td>
<td>°C</td>
<td>0.1×10⁶</td>
</tr>
<tr>
<td>Heat Conductivity</td>
<td>W/m°C</td>
<td>46.6</td>
</tr>
<tr>
<td>Shear Modulus</td>
<td>MPa</td>
<td>45×10³</td>
</tr>
</tbody>
</table>
6. Designing of Piston
The piston is designed by giving the dimensions into the modeling software PRO-E. The geometry of the piston is designed in PRO-E is imported to the analysis software in the IGES format. The figure of the designed piston is below-

7. Analysis of Piston
The piston is analyzed by giving the constraints they are
1. Pressure or structural analysis
2. Boundary condition
3. Thermal analysis 4. Thermo-mechanical analysis

7.1 Structural Analysis of Piston
Combustion of gases in the combustion chamber exerts pressure on the head of the piston during power stroke. The pressure force will be taken as boundary condition in structural analysis using ANSYS12 Workbench. Fixed support has given at surface of pin hole. Because the piston will move from TDC to BDC with the help of fixed support at pin hole. So whatever the load is applying on piston due to gas explosion that force causes to failure of piston pin (inducing bending stresses). Pressure acting on piston = 5 N/mm² as shown in Fig.7.1.1

Results of Structural (Pressure) Analysis of Piston

Fig.6.1 Design of Piston  
Fig.6.2 Meshed Model of Piston

Fig.7.1.1 Applied pressure with fixed support  
Fig.7.1.2 Equivalent (Von-mises) Stress  
Fig. 7.1.3 Stress probe 1
Maximum Equivalent Stress - 78.56 MPa

Bending Stress – 38.25 MPa

**Fig.7.1.4 Stress Probe 2**
Compressive Stress – 17.678 MPa

**Fig.7.1.5 Stress Probe 3**
Tensile Stress – 36.98 MPa

**Fig.7.1.6 Stress Probe 4**
Shear Stress – 3.45 MPa

7.2 Thermal analysis
As the material used for designing of piston is Cast Iron. For a cast iron piston, the temperature at the centre of the piston head (TC) is about 425°C to 450°C under full load conditions and the temperature at the edges of the piston head (TE) is about 200°C to 225°C.
7.3 Thermo-mechanical Analysis
In this analysis we apply both pressure and temperature on piston.
Pressure: 5 N/mm²
Temperature: – (200°C–500°C)
8. COMPARISON OF RESULT

Material – Cast Iron
Pressure – 5 MPa
Temperature – 280°C-500°C

Comparison of Analytical and FE Analysis results for piston

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Analytically Calculated Stress (MPa)</th>
<th>Stress by Fem Analysis (MPa)</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>36.62</td>
<td>38.24</td>
<td>4.23</td>
</tr>
<tr>
<td>Thermal</td>
<td>2.4</td>
<td>1.72</td>
<td>28.33</td>
</tr>
<tr>
<td>Thermo-mechanical</td>
<td>39.18</td>
<td>39.45</td>
<td>0.68</td>
</tr>
</tbody>
</table>

9. CONCLUSION

It is concluded from the above study that using PRO/E software design and modeling become easier. Here material used for Piston is Cast Iron because Cast Iron sustain more temperature than other material. The temperature distribution of piston is very important to check the effect of temperature is maximum on which part of piston. After the analysis of temperature distribution the result comes out that the maximum temperature is on the piston head and the minimum temperature is on the piston skirt.

The equivalent stress values obtained are well below the permissible value of 86MPa-100MPa. From the above result of comparison we conclude that analytical and FE analysis results for mechanical, thermal & thermo-mechanical loading are approximately similar. The percentile difference between analytical results & analysis results of piston are very small. Hence the design of piston is safe.

REFERENCES


